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COLORADO PEGMATITES

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INTRODUCTION

GENERAL DISTRIBUTION. Pegmatites are found in every county of Colorado along the Front Range of the Rocky Mountains from Larimer County on the Wyoming line to Custer County in the south-central part of the state, and in scattered pre-Cambrian areas to the westward. The various districts are briefly mentioned in the following paragraphs.

The pre-Cambrian schists and granites of Larimer County are cut by numerous pegmatite dikes[1] which have been exploited for mica southwest of Fort Collins.[2] Pegmatite dikes exhibiting an ore mineral phase occur in Boulder County.[3] Jefferson County contains both tourmaline and muscovite pegmatites.[4] Complex pegmatites with a magnetite phase occur in the Georgetown district of Clear Creek County.[5] A pegmatite pocket or cavity measuring 50 feet in length, 2 to 15 feet in width, and 4 feet (average) in depth was found on Devil's Head Mountain in southwestern Douglas County about 50 years ago. Within the pocket were crystals of topaz, microcline, cassiterite, and fluorite.[6] Pegmatites with a well developed fluorine phase occur in and associated with the Pike's Peak granite of western El Paso County, Teller County, and eastern Park County. Principal localities are St. Peter's Dome, Crystal Park, Cameron Cone, Pike's Peak, Florissant (Crystal Peaks), and Tarryall.[7] Western Park County contains numerous simple pegmatites.[8] Corundum and dumortierite occur in a pegmatite on Grape Creek in southern Fremont County.[9] Muscovite pegmatites, some with a beryllium phase, occur in three districts in Fremont County: Eight-Mile Park, the vicinity of Micanite (25 miles northwest of Canon City), and 6 miles north of Texas Creek.[10] The crystalline rocks of the Silver Cliff district of Custer County contain simple pegmatite dikes.[11]

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[1] Fuller, M. B., General features of pre-Cambrian structure along the Big Thompson River in Colorado: *Jour Geology,* vol. **32,** pp. 49–63, 1924. Boos, M. F., and Boos, C. M., Granites of the Front Range; the Log Cabin batholith: *Geol. Soc. Am.,* Abstracts 46th Ann. Meeting, p. 16, Dec. 28–30, **1933;** Granites of the Front Range; the Long's Peak-St. Vrain batholith: *Bull. Geol. Soc. Am.,* vol. **45,** pp. 303–332, April 30, 1934. Reed, T. T., Nodular bearing schists near Pearl, Colorado: *Jour. Geology,* vol. **11,** p. 493, 1903.

[2] Sterrett, Douglas B., Mica deposits of the United States: *U. S. Geol. Survey,* Bull. **740,** pp. 59–60, 1923.

[3] Lindgren, W., Some gold and tungsten deposits of Boulder County, Colorado: *Econ. Geology,* vol. **2,** pp. 453–463, 1907. Kirk, Charles T., Tungsten district of Boulder County, Colorado: *Min. and Sci. Press,* vol. **112,** pp. 791–795, May 27, 1916.

[4] Patton, H. B., Tourmaline and tourmaline schists from Belcher Hill, Colorado: *Bull. Geol. Soc. Am.,* vol. **10,** pp. 21–26, 1893. Sterrett, Douglas B., *Op. cit.,* pp. 57–58.

[5] Spurr, J. E., and Garrey, G. H., Preliminary report on the ore deposits in the Georgetown, Colorado, mining district: *U. S. Geol. Survey,* Bull. **260,** pp. 99–120, 1905; *U. S. Geol. Survey,* Prof. Paper **63,** p. 60 et seq.

Pegmatites likewise occur in central Colorado to the west of the Front Range. Examples are the simple pegmatites in the Montezuma mining district in Summit County,[12] in the Monarch district of Chaffee County,[13] and in the Bonanza district of Saguache

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[6] Smith, W. B., Contributions to the mineralogy of the Rocky Mountains: *U. S. Geol. Survey*, Bull. **20**, pp. 73–74, 1885.

[7] Cross, W., and Hillebrand, W. F., Contributions to the mineralogy of the Rocky Mountains: *U. S. Geol. Survey*, Bull. **20**, pp. 221–332, 1885. Finlay, Geo. I., Colorado Springs Folio: *U. S. Geol. Survey*, Folio **203**, 1916. Over, Edwin Jr., Mineral localities of Colorado (El Paso County): *Rocks and Minerals*, vol. **4**, no. 4, pp. 106–107, Dec., 1929. Palache, C., and Over, Edwin Jr., Pegmatites of the Pike's Peak region, Colorado: *Am. Mineral.*, vol. **18**, p. 115, 1933 (Abstract). Smith, W. B., Notes on the crystal beds of Topaz Butte: *Am. Jour. Sci.* (3), vol. **33**, pp. 134–135, 1887; *Proc. Colo. Sci. Soc.*, vol. **2**, pp. 103–115, 1886. Wulff, Willard, W., Topaz in the Tarryall Mountains of Colorado: *Rocks and Minerals*, vol. **9**, no. 4, pp. 45–47, April, 1934.

[8] George, R. D., Geology and ore deposits of the Alma district, Park County, Colorado: *Colo. Geol. Survey*, Bull. **3**, 1912. Singewald, J. D., Igneous history of the Buckskin Gulch stock, Colorado: *Am. Jour. Sci.* (5), vol. **24**, pp. 52–67, 1932.

[9] Finlay, Geo. I., On an occurrence of corundum and dumortierite in pegmatite in Colorado: *Jour. Geology*, vol. **12**, pp. 479–484, 1907.

[10] Sterrett, Douglas B., *Op. cit.*, pp. 50–56.

[11] Cross, W., Geology of Silver Cliff and Rosita Hills, Colorado: *U. S. Geol. Survey*, 17th Ann. Rept., Pt. 2, p. 279, **1896.**

[12] Patton, H. B., The Montezuma mining district of Summit County, Colorado: *Colo. Geol. Survey*, First report, pp. 105–144, **1909.**

[13] Crawford, R. D., A preliminary report on the geology of the Monarch mining district, Chaffee County, Colorado: *Colo. Geol. Survey*, Bull. **1** (19), pp. 1–78, 1910.

County.[14] Chaffee County also contains pegmatites with an ore mineral phase,[15] and (in the vicinity of Mount Antero) a well-developed beryllium phase.[16]

Pegmatites are not abundant in western Colorado where crystalline rock outcrops are relatively scarce. Both simple and complex (lithium) pegmatites occur in pre-Cambrian rocks exposed near Ohio City in eastern Gunnison County.[17] Muscovite pegmatites have been exploited in Mesa County, about 8 miles south of Grand Junction.[18] Relatively small dikes of simple pegmatite occur within the pre-Cambrian rocks of the Needles Mountains in southeastern San Juan County.[19]

The writer has visited and made extensive collections from a number of pegmatites in the Pike's Peak region (El Paso and Teller counties), in the valley of the Arkansas (Fremont and Chaffee counties), and in Gunnison County. These deposits are described in this paper.

FIELD WORK AND ACKNOWLEDGMENTS. The mineral deposits described in the following pages were studied during July in both 1932 and 1933. The field work the first summer was made possible through a grant from the Elizabeth Thompson Science Fund. A similar grant was made by the National Research Council for the 1933 field season. The writer wishes to express his gratitude to these organizations for their assistance. He is also grateful to General Superintendent W. J. Coulter and Chief Engineer Carl Cunningham of the Climax Molybdenite Company for courtesies received at Climax. The writer is indebted to Dr. John W. Vanderwilt for helpful suggestions made during the preparation of a preliminary draft of the manuscript, and to Mr. A. L. Morrow for assistance during the 1933 field season. The Graduate Research

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[14] Burbank, W. S., Geology and ore deposits of the Bonanza mining district, Colorado: *U. S. Geol. Survey*, Prof. Paper **169**, pp. 1–166, 1932.

[15] Crawford, R. D., Geology and ore deposits of the Monarch and Tomichi districts, Colorado: *Colo. Geol. Survey*, Bull. **4**, pp. 280–281, 1913.

[16] Over, Edwin, Jr., Mineral localities of Colorado: *Rocks and Minerals*, vol. **3**, no. 4, pp. 110–111, 1928. Penfield, S. L., Some observations on the beryllium minerals from Mt. Antero: *Am. Jour. Sci.* (3), vol. **40**, pp. 488–491, 1890.

[17] Eckel, Edwin B., A new lepidolite deposit in Colorado: *Jour. Am. Ceramic Soc.*, vol. **16**, no. 5, pp. 239–245, May, 1933.

[18] Sterrett, Douglas B., *Op. cit.*, pp. 61–62.

[19] Cross, Whitman, Fluidal gneiss and contemporaneous pegmatites (Abstract): *Science*, n.s., vol. **29**, p. 946, 1909.

Committee of the University of Kansas supplied a refractometer and a sodium light which materially increased the accuracy of the optical data obtained.

Pike's Peak Region

St. Peter's Dome Cryolite Locality. Several pegmatite veins containing cryolite and associated fluorides occur on the north flank of St. Peter's Dome. This is one of the very few cryolite localities of the world. The deposit visited by the writer is a short distance north of the east portal of a tunnel on the Corley Mountain toll road. This tunnel, which cuts through a northward-trending spur of St. Peter's Dome, is shown on the Manitou topographic sheet as a tunnel on the Cripple Creek railroad. It is 10.3 miles above the first toll gate out of Colorado Springs.

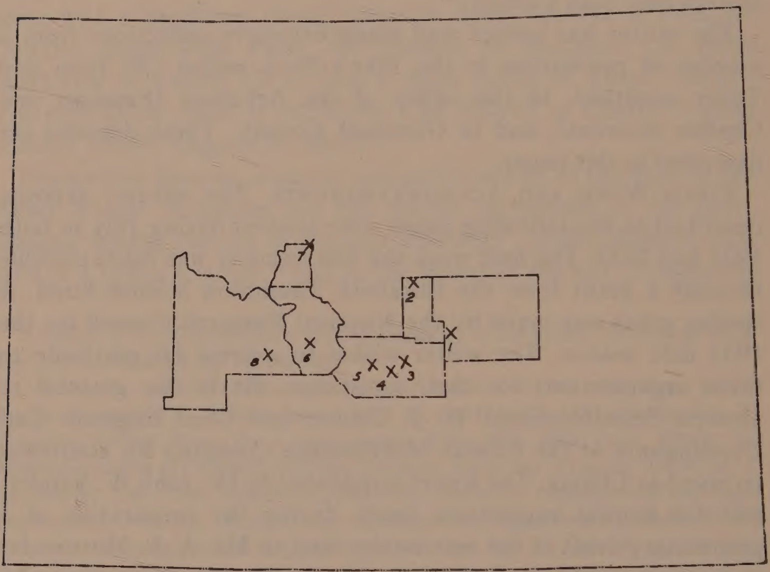

Fig. 1. Outline map of Colorado, showing location of deposits described in this paper. Key to numbers: (1) St. Peter's Dome (El Paso County), (2) Florissant (Teller County), (3) 8-mile Park (Fremont County), (4) "Pegmatite" (Fremont County), (5) Texas Creek (Fremont County), (6) Mt. Antero (Chaffee County), (7) Climax (Lake County), (8) Ohio City (Gunnison County).

The pegmatite was opened up many years ago by a tunnel which has since caved. Most of the writer's collecting was done on the dump. The pegmatite strikes north and south and dips steeply into the hill (west). It is about 3 feet thick at the outcrop. The dominant minerals are white bull quartz, microcline in large masses, and long prismatic crystals of riebeckite. The fluorides, which are white in color except where purple fluorite is abundant, are decidedly subordinate quantitatively, occupying but a small part of the pegmatite. Aplite, consisting mainly of quartz, feldspar, and riebeckite, occupies a narrow zone along the footwall of the pegmatite. The country rock is the Pike's Peak granite, a coarse rock composed of greenish feldspar, quartz, and biotite.

The following paragraphs describe the minerals occurring in the pegmatite.

The *feldspar* is entirely microcline, except for a subordinate amount of perthitically intergrown albite. The microcline varies in color from pink to dark-red. Cleavage faces 10 cm. long are common. The contact between the microcline and the fluorides in some specimens is a smooth plane parallel to one of the cleavage directions of the feldspar; in others the fluoride-depositing solutions have attacked the feldspar, forming deep reentrants into it and in a few cases completely cutting through a microcline crystal. The *quartz* is milky. One quartz specimen collected exhibits a remarkably good cleavage (for this mineral), and the surrounding and encroaching fluorides have preserved the cleavage in "ghost" form. A black prismatic mineral which occurs completely surrounded by fluorides is probably *riebeckite*. It is so weathered as to be practically opaque, but the prismatic characteristic of the amphiboles is still recognizable.

The fluorides will be described in the order in which they were formed. The solutions from which each of the fluorides were precipitated first followed fractures and other directions of easy penetrability and then worked outward into and replacing the older minerals. The fluorides, with the exception of fluorite, are white in color and not readily distinguishable. Only a small proportion of the white material collected proved to be *cryolite*. The freshest specimens of cryolite are pale-gray and translucent. Alteration along cleavage planes gives this mineral a banded appearance which aids in its identification. Crushed fragments of the fresh cryolite show beautiful polysynthetic twinning under the microscope. Most of the cryolite collected is severely kaolinized and ranges in color from white to pink. Other fluorides are almost invariably associated. The commonest of these, and the most abundant mineral in the pegmatite other than feldspar and quartz, is *pachnolite*, $NaF\cdot CaF_2\cdot AlF_3\cdot H_2O$. This mineral is white (rarely pale-green) and opaque in the hand specimen. Crushed fragments gave the following optical data under the microscope: biaxial positive; $\alpha=1.407\pm.003$; $\gamma=1.418\pm.003$; cleavage indistinct. Polysynthetic and even gridiron twinning are visible in a few grains. All stages of hydrothermal replacement between pure cryolite and completely pachnolitized cryolite were found among the specimens collected. Where replacement is partial only the specimen is translucent; where complete it is chalky. The contact between the cryolite and the feldspar is especially liable to be occupied by pachnolite (and fluorite) veins. The pachnolite is partially kaolinized in many of the specimens collected.

Prosopite, $CaF_2\cdot 2Al(F, OH)_3$, ordinarily occurs in glassy colorless blades, exhibiting a good cleavage parallel to the blade surface. Optical data follow: biaxial positive, $n=1.50$; birefringence $=.009$. This material occurs as scattered blades or bundles of blades in the earlier fluorides, or in veins which either follow the contact between the earlier fluorides and feldspar or cut through the cryolite and pachnolite. A small amount of prosopite appears in very dense translucent masses. The color is white unless impurities are present. Scattered minute fluorite grains may give the mass a light-purplish color. Iron oxide has stained some of the prosopite red. Part of a microcline crystal in one specimen has been replaced by prosopite, the latter, exhibiting the cleavage of the feldspar in ghost form. In this instance the red color of the prosopite appears to be residual from the microcline. The prosopite is remarkably free from supergene alteration.

Fluorite occurs both finely disseminated and in veins. The latter are especially abundant along contacts, such as those between the fluoride masses and the feldspar, but fluorite veins also occur cutting cryolite and pachnolite. One such vein is over a centimeter thick. In most cases the fluorite is purple, but one specimen of fluoritized cryolite is pale greenish-white in color.

Siliceous solutions have caused the replacement of some of the fluorides by *chalcedony*, producing a very hard sugary mass. The host minerals to the chalcedony were in most cases prosopite and cryolite, but in one specimen a fluorite-prosopite aggregate has been silicified. All stages may be found between incipient and complete chalcedonization of the prosopite and cryolite. Kaolinization has affected the microcline, cryolite, and pachnolite. Cryolite is in the majority of specimens more kaolinized than the pachnolite. A very thin vein of *kaolinite* cuts a vein of fluorite in one specimen. The mean index of refraction of this kaolinite was 1.564.

The fluorides are distinctly later than the feldspar and quartz, penetrating the latter in veins and wedge-shaped masses in several specimens. The smooth contacts between the fluorides and the microcline (parallel to a cleavage direction in the latter mineral) seen on some specimens may be due to dissolution along planes of weakness in the feldspar. Additional evidence of the later deposition of the fluorides lies in the concentration of this material in "shoots" which occupy but a small proportion of the total volume of the pegmatite.

The writer concludes that first the feldspar, quartz, and probably the riebeckite crystallized from a pegmatite magma which was an offshoot of the Pike's Peak batholith. After the solidification of this primary pegmatite, hydrothermal solutions rich in fluorine released from deeper crystallizing magma travelled up through the pegmatite and replaced a part of the earlier minerals with fluorides. The fluorides were deposited in the following order: cryolite, pachnolite, prosopite, and fluorite. A small amount of silicification closed the period of hydrothermal mineralization. The kaolinization was caused by supergene solutions.

That more than one period of mineralization is involved in the St. Peter's Dome fluoride pegmatites was recognized by Cross and Hillebrand[20] in 1885: "Some of these veins have certainly had two periods of secretion, as is shown in the Eureka tunnel, St. Peter's Dome."

There must have been an abundance of fluorine in the Pike's Peak granite magma. The fluorides occurring in the pegmatite just described and in others in the immediate vicinity are one manifestation of this. Another is the presence of fluorite in nearly solid veins at several places on the east flank of St. Peter's Dome. And of greatest importance is the presence of fluorite as an accessory mineral in the Pike's Peak granite itself.[21] One result of the presence of this fluorine-rich rock in the drainage basin contiguous to Colorado Springs is the prevalence of "mottled enamel," a disfiguring disease of the teeth caused by fluorine in the drinking water, among the children of that city.

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[20] Cross, W., and Hillebrand, W. F., Contributions to the mineralogy of the Rocky Mountains: *U. S. Geol. Survey*, Bull. **20**, p. 42, 1885.

[21] Boos, Margaret Fuller, Granites of the Front Range; the heavy minerals: (Abstract) *Proc. Geol. Soc. Am.*, **1933**, p. 67.

Another element present in greater than average amount in the original magma was zirconium. A zircon-quartz pegmatite occurs a few hundred yards to the southeast of the fluoride pegmatite, and zircon is a fairly common mineral in the rocks of this region. The origin of the zircon has been discussed by Palache and Over[22] and a paper on the subject is anticipated.

FLORISSANT. A group of pegmatites lies about 8 miles (by road) north of Florissant. This is the locality known in the early literature as "Topaz Butte" and "Crystal Peaks,"[23] and now locally referred to as the "Gem Mines." Mr. A. B. Whitmore has opened up several of the pegmatites from which he obtains quartz and amazonstone crystals which he sells to visitors.

According to W. B. Smith crystal-bearing pegmatites are abundant over a rectangle which measures 3 miles east and west and 6 miles north and south, and has its southern edge about 5 miles due north of Florissant. The Crystal Peaks, a group of bare granite peaks, lie within this rectangle. A dominant feature of the pegmatites is the common occurrence within them of pockets or cavities which are invariably lined with quartz and microcline crystals and, more rarely, phenacite and topaz. A crystal quarry near Whitmore's cabin affords an excellent opportunity to observe the field relationships. The country rock is a severely disintegrated granite which is cut by small and erratic pegmatite stringers. Within the latter are cavities up to 30 feet in length which are lined with drusy microcline and quartz crystals. Some of the pockets pinch completely shut and then open up again farther along the same plane. A zonal arrangement was noted in these pegmatites. Immediately adjacent to the disintegrated granite walls are bands of graphic granite about 8 inches across. These are succeeded (toward the center of the pegmatite) by zones from 2 to 4 inches wide of massive feldspar and quartz with a few small books of muscovite. Crystals on the inside walls of this zone project into the cavity which occupies the center of the pegmatite.

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[22] Palache, C., and Over, Edwin, Jr., Pegmatites of the Pike's Peak region, Colorado: (Abstract) *Am. Mineral.*, vol. **18**, p. 115, 1933.

[23] Smith, W. B., Notes on the crystal beds of Topaz Butte: *Am. Jour. Sci.* (3), vol. **33**, pp. 134–135, 1887.

No amazonstone was observed in the graphic granite or massive spar zones except near a cavity wall. The *microcline* in the "primary" pegmatite is white or pink and the *quartz* is milky. The microcline crystals lining the vug walls are dominantly amazonstone, but white and cream-colored crystals are likewise present. A very small amount of *albite* (cleavelandite) was found replacing amazonstone. The drusy quartz is colorless, milky, smoky, and (rarely) amethystine. A few very minute colorless and reddish *phenacite* crystals were found perched upon rhombohedral faces of quartz crystals. One large milky quartz crystal is in part coated by a minutely reniform black crust of *manganite.*

Unusually fine specimens of graphic granite are obtainable from these pegmatites. In one specimen collected by the writer the feldspar has been etched out to a depth of 1 to 3 mm., leaving the quartz hieroglyphs in a bas-relief. The quartz occurs in crystals which are euhedral but severely distorted, in many cases flattened parallel to a pair of rhomb faces. A wide variety of shapes is exhibited by the hieroglyphs. The quartz crystals vary in maximum dimension from 1 to 23 mm. Over relatively large portions of the specimen the faces on the quartz crystals are parallel (but in different planes) so that light is simultaneously reflected from each individual among a mass of hieroglyphs. In one part of the specimen rhomb faces of the quartz crystals are approximately parallel to the etched surface of the microcline, in another part prism faces parallel this surface. The feldspar is too badly weathered to permit determination of its orientation, but it appears to be a single individual with a dominant cleavage parallel to the general surface of the specimen. Apparently the atomic structure of the feldspar had a dominating control on the position and orientation of the quartz "guests."

The writer suggests the following sequence of mineralization for the Florissant pegmatites:

1. Intrusion of the primary pegmatite magma into the granite country rock.

2. Cooling and crystallization of this magma, producing white or pink microcline, milky quartz, and muscovite (in very minor amounts). The quartz did not commence to crystallize until some of the feldspar had already been precipitated in the border zones. This microcline was replaced in part by quartz, forming graphic granite. Farther toward the center of the pegmatites the crystal-

lization of the two dominant minerals overlapped, resulting in a mixture of anhedral crystals.

3. The cavity stage. Either the not yet solidified magma in the center of the pegmatites drained on out of certain portions leaving flattened lens-like openings or else subsequent corroding hydrothermal solutions used this part of the mineral deposit as a channelway. In either case very narrow and elongate cavities resulted.

4. Hydrothermal replacement phase. In most pegmatites this phase is dominated by deposition of soda feldspar. At Florissant, however, the residual pegmatitic solutions were unusually high in potash, so that crystals of microcline (much of it the green amazonstone) were deposited along the cavity walls, in part replacing the pegmatite wall rock. At the same time variously colored quartz crystals were deposited. Some of these root into the walls in rods which give certain sections of the cavity wall rock a graphic texture, much poorer in quality, however, than that of the outer graphic granite zone. During later stages of this phase a little albite was deposited, replacing amazonstone, and the phenacite crystals were precipitated on the quartz faces.

5. Supergene phase. Ground waters have deposited manganite, and the feldspars have been partially kaolinized.

ARKANSAS RIVER VALLEY

EIGHT-MILE PARK. Eight-Mile Park lies immediately north of the Royal Gorge of Arkansas River, about 8 miles by road from Canon City. The Arkansas River flows through sedimentary rocks both above and below Royal Gorge, but at the Gorge the river cuts through an up-pushed mass of pre-Cambrian granite.[24] Eight-Mile Park is the wooded rolling eroded surface of this crystalline rock mass. Pegmatites are abundant in the Park. Most are simple in composition and small in size, but two are sufficiently large to have been opened up for mica and feldspar. These are the Myers-Halstead quarry and the Mica Hill deposit. Both are reached by a road which runs south from U. S. Highway 50 from a point about 1½ miles east of the Royal Gorge airport. Mica Hill lies a few hundred yards west of the Myers-Halstead quarry and overlooks the Priest Canyon road from the Gorge rim to Canon City.

Feldspar is the dominant constituent of both pegmatites, forming masses (but not single crystals) 40 to 50 feet across. Quartz is second in order of abundance. It appears in masses of irregular shape; most of which measure but a few inches across, but some are several feet in maximum dimension. Muscovite is present in sufficient amount to yield commercial mica. It occurs in books of relatively small size, but these books form aggregates of pure mica as much as 10 feet across. A small amount of beryl was found in the Myers-Halstead pegmatite, but none was observed at Mica Hill. The latter deposit contained a small amount of malachite. As no primary copper minerals were found in the pegmatite, it is possible that the country rock was the source of the copper.

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[24] Campbell, M. R., Guidebook of the Western United States, Part E, the Denver and Rio Grande Western route: *U. S. Geol. Survey*, Bull. **707**, pp. 79–80, 1922.

Two varieties of feldspar, microcline and albite, are present in the Myers-Halstead pegmatite. The *microcline* occurs in large red subhedral crystals. It is perthitic, but the albite lamellae are very thin and decidedly subordinate. Post-perthite *albite* is very abundant in some parts of the quarry. This albite is pink, and can be readily distinguished from the microcline by its lighter shade. Two generations of *quartz* are present; the earlier is massive, while the later generation occurs in rods, veins, and subhedrons. Both types are milky in color. The *muscovite* is silvery, and tends to form wedge and fan-shaped aggregates. A light yellowish-green sericitic mica is also present. *Beryl* varies from cream to light-green in color. It is invariably in small prismatic crystals, which may group together into slightly radiating bundles. *Tourmaline* is decidedly subordinate. It occurs in very dark-blue crystals and is opaque in the hand specimen.

The outstanding feature in the paragenetic history of these pegmatites was albitization. This followed the magmatic phase during which muscovite, tourmaline, microcline, and first generation quartz crystallized out. Between the magmatic phase and the albitization a small amount of beryl was deposited. Post-albitization mineralization was confined to hydrothermal deposition of a second generation of quartz, and last of all, the precipitation of sericite. In places the quartz so replaces the albite as to produce graphic texture. Some of the quartz rods are subhedral, exhibiting striated prism faces. Such rods are not elongated parallel to a crystallographic axis, but may be parallel to the rhombohedral face edges, which have not been developed. Both the elongated crystals and the quartz veins tend to follow cleavage directions in the host feldspar.

"PEGMATITE." On the Denver and Rio Grande railroad above the Royal Gorge and 2½ miles below the station of Echo is the abandoned station of Pegmatite. The mineral deposit which gave the station its name is situated near the top of a high hill south of the river, and is reached by a trail which leads from a group of buildings along the highway. The deposit consists of lit-par-lit injections of pegmatite into schist. A 500-foot tunnel has been driven into the hill, cutting through several bands of pegmatite of variable thickness. These bands consist mainly of white and pink feldspar with scattered small books of mica. Quartz is subordinate.

The paragenesis at "Pegmatite" is relatively simple. However, the relationship between the *microcline* and the *quartz* is interesting. All stages are present between graphic granite and quartz-veined feldspar. One specimen collected by the writer is a large cleavage fragment of flesh-colored microcline which is cut by many thin parallel quartz veins. These range mostly from one-half to 1 mm. in thickness, and the maximum is 3 mm. Some veins disappear completely, others taper out and reappear again. These veins are roughly parallel to the brachypinacoidal cleavage. They do not follow exact planes; minor irregularities in direction occur, and in a few instances one vein branches out from another for a short distance and then follows a parallel course. In other specimens the quartz veins were much less consistent in length, and more apt to turn and follow some other molecular plane, such as the direction of prismatic cleavage. The result, when viewed on the basal cleavage, is a graphic texture. In the writer's opinion, the most plausible explanation of this phenomenon is that the microcline crystallized first and that the quartz-depositing solutions followed planes of weakness in the microcline.[25] It must be remembered that graphic structures are viewed in two dimensions only and when the third dimension is examined the quartz is usually found to be decidedly elongated.

Both *biotite* and *muscovite* are present in minor amounts in this deposit. Some of the muscovite is light greenish-yellow in color, occurring in very fine scales and flakes.

TEXAS CREEK. This deposit lies about 6 miles north of Texas Creek, a station on the Denver and Rio Grande railroad between

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[25] Schaller, W. T., Mineral replacement in pegmatites: *Am. Mineral.*, vol. **12,** p. 61, 1927. Landes, K. K., The Baringer Hill, Texas, pegmatite: *Am. Mineral.*, vol **17,** p. 383, 1932.

Canon City and Salida. A trail runs from the mine to Texas Creek, and a secondary road connects the ore bins below the mine with Echo station. The pegmatite crops near the top of a hill about 300 feet above the floor of East Gulch. It has been mined to a small extent and a tram connects the open cut with the bottom of the gulch.

The Texas Creek pegmatite is composed mainly of pale-pink feldspar. Quartz, both milky and rose, is present in large isolated masses. Sterrett[26] reports one of these as 150 feet long and 20 feet high. Muscovite aggregates are present in streaks and masses up to 4 feet across. *Beryl* and *tourmaline* are accessory minerals.

The principal feldspar is *microcline*. It ranges in color from white to red, but pale salmon pink predominates. Most of the microcline is perthitic, with the albite percentage varying between 10 and 30. The microcline encroaches upon the muscovite. Later albitization has been an important process in the history of the Texas Creek pegmatite. A part of the perthite is extensively replaced, and thin veins of *albite* extend out beyond the replaced portions into the older feldspar. Books of *muscovite* are likewise invaded by albite veins which both parallel and cut across the mica sheets. The albite is the cleavelandite variety. Albitization was accompanied by the precipitation of silvery sericitic mica along cleavage planes in the earlier minerals. *Quartz* also appears in two generations. Most of it occurs in large anhedral masses of milky or rose color which are cut by veins of albite. The later (hydrothermal) quartz forms thin veins which traverse all of the other minerals including the cleavelandite.

Mineralization during the magmatic phase included the precipitation of tourmaline and muscovite followed by microcline (perthite) and quartz. Beryl is probably early hydrothermal. Its formation was followed by albitization and minor sericitization. Vein quartz was the last mineral to be deposited.

MOUNT ANTERO. Since 1887 Mt. Antero has been known as a source of fine aquamarine gems occurring in pegmatites. Associated with the aquamarines are phenacite, bertrandite, and fluorite. These minerals are found at a number of points at high elevation on Mt. Antero and on Mt. White, one of its spurs.[27]

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[26] *Op. cit.*, p. 56.

[27] Cross, R. G., Notes on aquamarine from Mt. Antero: *Am. Jour. Sci.* (3), vol. **33**, pp. 161–162, 1887. Smith, V. G., Mineralogical notes—Nos. 1, 2 and 3;

The writer in attempting to find these pegmatites, was misdirected to an abandoned molybdenite mine situated in the headwaters amphitheatre of Browns Creek, a tributary of the Arkansas which drains the southern slopes of Mount Antero. This molybdenite deposit proved very interesting and has been described in a separate paper.[28] *Molybdenite* and *beryl* (some of which is aquamarine) occur together in a *quartz* vein. In all likelihood the deposition of the beryl-molybdenite vein and the formation of the beryl-phenacite-bertrandite pegmatites of Mount Antero belong to the same general period of mineralization. Beryllium was present among the "fugitive" elements of a near-by crystallizing magma in unusual proportions, so appears as an essential constituent in minerals present in both the pegmatites and in hydrothermal veins which were formed during the expiring phases of the igneous activity.

Climax. The Climax molybdenite property at Climax, Colorado, was visited during the 1933 field season. This trip was made because two writers[29] have classified the Climax deposit as a pegmatite. However, neither the field study nor the examination of rock and mineral specimens collected bear out this contention. The mineral grains in the Climax ore body are very small. Furthermore, a magmatic phase is absent; the mineralization was accomplished entirely by hydrothermal solutions. The presence of orthoclase, muscovite, and topaz in the Climax deposit is no more indicative of pegmatites than of hydrothermal veins. Butler and Vanderwilt,[30] who have intensively studied this deposit, consider that it was formed under conditions which were transitional between hypothermal and mesothermal.

Proc. Colo. Sci. Soc., vol. **2**, pp. 177–179, 1887. Penfield, S. L., Phenacite from Colorado: *Am. Jour. Sci.* (3), vol. **33**, pp. 131–134, 1887; Bertrandite from Mt. Antero: *Am. Jour. Sci.* (3), vol. **26**, pp. 52–55, 1888; Some observations on the beryllium minerals from Mt. Antero: *Am. Jour. Sci.* (3), vol. **40**, pp. 488–491, 1890. Penfield, S. L., and Sperry, E. S., Mineralogical notes: *Am. Jour. Sci.* (3), vol. **26**, p. 32, 1888. Over, Edwin, Jr., Mineral localities of Colorado: *Rocks and Minerals*, vol. **3**, pp. 110–111, 1928.

[28] Landes, Kenneth K., The beryl-molybdenite deposit of Chaffee County, Colorado: *Econ. Geology*, vol. **29**, pp. 697–702, 1934.

[29] Locke, A., Review of paper written by Butler and Vanderwilt: *Econ. Geology*, vol. **27**, no. 1, pp. 99–102, 1932. Lindgren, W., *Mineral Deposits*, 4th ed., p. 770, 1933.

[30] Butler, B. S., and Vanderwilt, J. W., The Climax molybdenite deposit of Colorado: *Proc. Colo. Sci. Soc.*, vol. **12**, no. 10, pp. 309–353, 1931. *U. S. Geol. Survey*, Bull. **846–C**, pp. 195–237, 1933.

GUNNISON COUNTY

OHIO CITY. The most interesting of the Colorado pegmatites visited by the writer are in the valley of the Gunnison about 2 miles southwest of Ohio City. These have been recently described by Eckel.[31] Three parallel pegmatite dikes, each about 11 feet in width, constitute the main group. The country rock is pre-Cambrian schist, but intrusive granite, which Eckel suggests is genetically related to the pegmatites, outcrops a short distance to the southwest. Other pegmatite dikes, most of them simple in type, occur in the vicinity.

The main (Brown Derby) pegmatites are complex, with a strong lithium base. The principal minerals are *quartz*, *albite* (cleavelandite variety), *lepidolite*, *topaz*, and *beryl*. *Microcline* and *tourmaline* are subordinate. *Columbite* and *samarskite* are minor accessory minerals. The lepidolite occurs both in fine-grained masses and in lilac-colored books measuring several inches across. Topaz is unusually abundant, appearing in large rough milky crystals. Beryl likewise occurs in relatively large crystals and masses. The color varies from pink to aquamarine. Two varieties of tourmaline are present: common black, and the pink rubellite. The latter is probably lithium bearing.

Abundant evidence of hydrothermal replacement is present in the Brown Derby pegmatites. The replacement of the primary minerals of the pegmatites by albite took place on such a large scale that but little microcline is left in the main dikes. The introduction of the rare element minerals and a second generation of tourmaline (the rubellite) accompanied the albitization. Eckel[32] expects to publish a detailed account of the paragenesis of these pegmatites at a later date.

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[31] Eckel, Edwin B., A new lepidolite deposit in Colorado: *Jour. Am. Ceramic Soc.*, vol. **16**, no. 5, pp. 239–245, 1933.

[32] Eckel, Edwin B., Letter to the writer dated June 22, 1933.

DISTRIBUTION OF THE HEAVY MINERALS IN THE CLAYS OF MIDDLESEX COUNTY, NEW JERSEY

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SUMMARY

Elutriation of Cretaceous clay samples selected from the various stratigraphic horizons in Middlesex County, New Jersey, has afforded the material for the present petrographic research. Locations are shown on Plate 1. The main facts are the following:

1. The sandy residues from these clays have been studied in detail and the various grain sizes determined in their stratigraphic and areal distribution.
2. The various minerals, other than kaolin and quartz, have been identified.
3. The percentages of ilmenite, tourmaline, and zircon have been especially determined throughout the clay series and their relationships plotted stratigraphically and areally; this has made possible the correlation of clay beds whose exact relationships were hitherto unknown.
4. Total content of organic carbon has also been determined, and the relationships plotted in the same way as those of the heavy minerals.
5. The areal distribution of the various above-mentioned minerals and their relationships show that there is a distinct fan-like distribution of the clays; that the source of the material was from the northwest; and that it was carried by a definite river of very considerable size and drainage area.

INTRODUCTION

On the inner portion of the coastal plain of New Jersey, in the area within ten miles, more or less, of Perth Amboy, clays and sands have been extensively quarried for many years. The clays are used in the manufacture of fire-brick, hollow tile and stoneware; the sands, chiefly for building and road construction. They belong in age to the lower part of the Upper Cretaceous,[1] and include the following formations, beginning with the youngest in age:[2]

a. The Cliffwood clays, containing some glauconite, originally called the Clay-Marl series.

b. Laminated Sands, No. 4, showing thin clay layers and lenses.

c. The Amboy Stoneware clays, also very discontinuous; lenses in sand.

d. Sand Bed No. 3.

e. The South Amboy fire-clays, variable, lenticular and much replaced by and mingled with the sands above and below.

f. Sand No. 2, containing the so-called "Feldspar" and "Kaolin" Beds, which are lenticular bodies of white clay and partly disintegrated granitic gravel.

g. The Woodbridge clays, the most continuous formation of the series.

h. Fire Sand, No. 1, a formation which carries the artesian water of this vicinity.

i. The Raritan fire and terra-cotta clay, which consists of a series of discontinuous deposits in hollows in the bed-rock, and often grades into the latter.

It was thought that due to the extremely fine and complete water-sorting which the materials of these clays underwent during deposition, and the evidently undisturbed condition of most of them since that time, they should prove excellent subjects for quantitative microscopic study. This supposition has been largely supported by the results of the present research.[3] As the clays do not require crushing before they are submitted to the elutriation process, their grains appear unbroken when examined microscopically. This, it is obvious, has many advantages.

The clays of this Cretaceous series, of which about 40 samples from various horizons were studied, are highly plastic, and the finer grades of many of them contain practically no grit which may be felt when they are rubbed between the fingers. They are composed of kaolin, hydrated micaceous products, muscovite and similar material in grains of microscopic to submicroscopic size; and a proportion of fine-grained, angular sandy component which ranges in these samples from 12 to 69 per cent or more. The sandy material consists for the most part of sharp quartz grains (rounded grains are rare); in it are also found, as described in a former article published by the present writer,[4] the following minerals: magnetite, ilmenite, hematite, limonite, garnet, pyrite, zircon, rutile, tourmaline, etc., and pseudomorphs (evidently a kaolin mineral) after gypsum crystals. It seemed desirable to the writer to make quantitative determinations and measurements of these minerals, especially the ones which are most constantly present in the samples, in order to discover their relation to the story of the deposition of the clays. To this end, elutriation of the clays was undertaken, with the object of separating the granular portion from the lighter clay residue. All of the elutriation was done for the writer by the Department of Ceramics of Rutgers University, by Mr. John C. Gallup, under the direction of Professor George H. Brown. Each of the clay samples was washed through an apparatus composed of three small containers of graduated sizes, in which the rate of water flow was a known factor. Container No. 1, the largest, has a water velocity of 15 mm. per second, and the maximum size of grain of material retained in it is .04 mm. Container No. 2, with a water velocity of 0.7 mm. per second, retains grains of a maximum size of .025 mm., while No. 3 has a water velocity of 0.18 mm. per second and the maximum grain size retained is .01 mm. The size of grain will vary somewhat in practice, as it depends upon the specific gravities of the different minerals involved. The samples thus obtained were carefully weighed by Mr. Gallup, and delivered to the writer, who has tabulated the results. Later the samples were subjected to detailed microscopic study, during which many thousands of measurements and counts have been made. The conclusions reached are stated below.

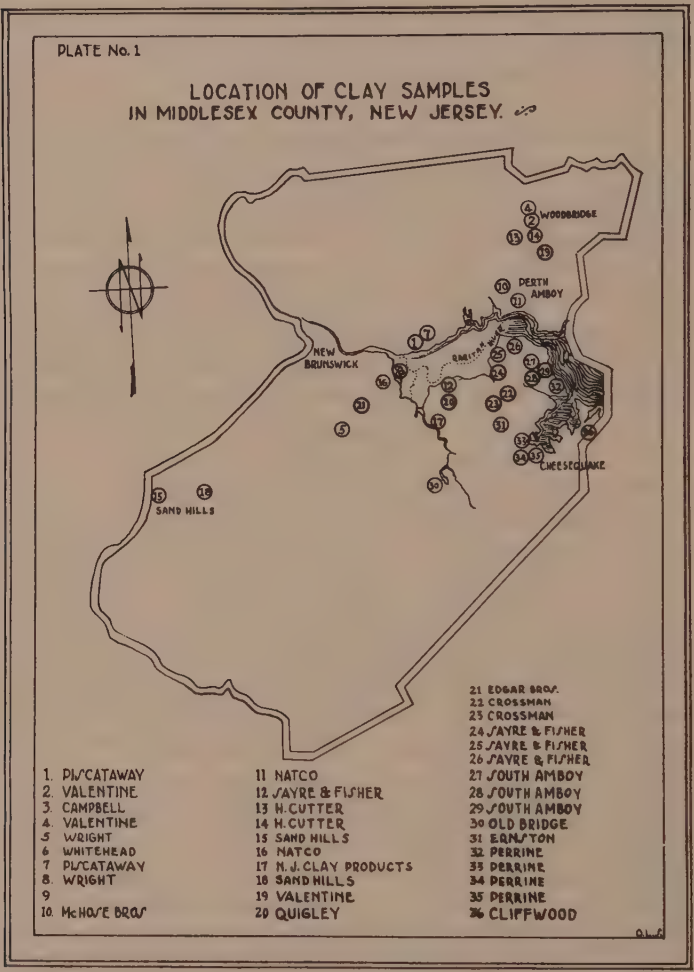

PLATE 1

HEAVY MINERALS IN THE CLAYS

There is, in each of the clays examined, a certain percentage of sandy material, which can be separated from the clay by elutriation. This material is largely composed of angular quartz grains. With the quartz there are also grains of the heavier and more unusual minerals, including such species as tourmaline, garnet and pyrite. Discarding the mineral pyrite, which is secondary, we find that there are a few characteristic minerals which are consistently present throughout the whole clay series. These minerals, of which there are three principal ones, have been quantitatively measured and the results plotted vertically and horizontally (areally) through out the clays. Consideration has also been given to the relations of these minerals to the kaolin mass of the clay itself. Chemical analyses to determine the distribution of the total organic carbon in the clays have also been made, and the results plotted.

Details of tests made and results obtained are given in Tables I and II.

TABLE I

PERCENTAGE OF SAND GRAINS OF VARIOUS SIZES OBTAINED FROM ELUTRIATION OF CLAYS

	Number and Location of Sample	Percentage by weight of residue				Percentages recast to 100%		
		Can 1	Can 2	Can 3	Total	Can 1	Can 2	Can 3
					%			%
Marine Beds. (Upper Cretaceous and Tertiary)	38. Upper Marl, Neptune, N. J.	28.20	26.22	14.10	68.52	41	38	21
	37. Middle Marl, Middletown, N. J.	40.05	25.02	18.10	83.17	48	30	22
	36. Cliffwood Clay (Oschwald) Keyport	27.65	2.54	27.20	57.39	47	6	47

TABLE I (*Continued*)

	Number and Location of Sample	Percentage by weight of residue				Percentages recast to 100%		
		Can 1	Can 2	Can 3	Total	Can 1	Can 2	Can 3
Amboy Stoneware Clays	35. Perrine Top Sand Clay, Cheesequake.	27.30	2.94	28.50	58.70	46	5	49
	34. Perrine Gray Clay Cheesequake.......	2.65	.71	27.28	30.64	9	2	89
	33. Perrine Red Mottled Cheesequake.......	2.15	7.20	12.30	21.65	11	33	56
	32. Perrine Gray Clay Morgan..........	.25	10.44	27.00	37.69	1	27	72
	31. Smith Gray Clay Ernston..........	2.10	7.80	27.20	37.20	6	21	73
	30. Raritan Sand Co. Gray Old Bridge....	4.54	12.92	28.55	46.00	10	28	62
	29. Old Prospect Pits, Red South Amboy..	12.17	1.62	31.17	44.96	27	4	69
	28. Old Prospect Pits, Yellow South Amboy	5.15	.76	15.75	21.66	24	3	73
	27. Old Prospect Pits, White South Amboy	1.43	5.43	24.47	31.33	4	17	78
South-Amboy Fire-Clays	26. Sayre & Fisher, Dark Gray, West of South Amboy..........	16.76	15.00	25.50	50.48	30	28	42
	25. Sayre & Fisher, Light Gray, West of South Amboy..........	7.50	4.00	5.97	17.47	43	23	34
	24. Sayre & Fisher, Light Gray, Burt Creek...	15.43	.51	3.26	19.20	81	2	17
	23. Crossman, Gray Clay Parlin...........	.36	26.30	29.62	56.28	1	47	52
	22. Crossman Red Mottled Parlin.........	.18	.60	7.68	8.46	2	7	91
	21. Edgar Bros. Light Gray Milltown.....	4.04	2.31	18.59	24.94	17	9	74

TABLE I (*Continued*)

	Number and Location of Sample	Percentage by weight of residue				Percentages recast to 100%		
		Can 1	Can 2	Can 3	Total	Can 1	Can 2	Can 3
"Feldspar" Beds	20. Quigley White Clay Sayreville	.32	5.21	16.70	22.23	2	23	75
	19. Valentine (Feldspar) Woodbridge	.15	8.43	22.14	30.72	1	27	72
	18. Route 25 White Clay Sand Hills	.50	18.98	25.94	45.42	1	42	57
Woodbridge Fire-Clays	17. N. J. Clay Prod. Co. Gray, So. of Sayreville	7.65	20.09	41.15	68.89	11	29	60
	16. Natco, Gray West of So. River	1.47	6.58	39.15	47.20	3	14	83
	15. Lincoln Highway Gray, Sand Hills	2.50	1.25	8.35	12.10	21	10	69
	14. Hampton Cutter Gray Woodbridge	2.50	2.10	55.50	60.10	4	3	98
	13. Hampton Cutter Gray, Woodbridge	.55	4.20	39.25	44.00	2	9	89
	12. Sayre & Fisher Gray Sayreville	.23	9.27	43.31	52.81	1	17	82
	11. Natco Gray, Perth Amboy	4.12	10.88	44.60	59.60	7	17	76
	10. McHose Bros. Gray Keasby	4.36	10.55	41.60	56.51	7	19	74
Glacial (?) Clay	9. Gray Clay in Drift Elizabeth (glacial)	5.00	14.00	32.40	51.40	10	27	63

Table I (*Continued*)

	Number and Location of Sample	Percentage by weight of residue				Percentages recast to 100%		
		Can 1	Can 2	Can 3	Total	Can 1	Can 2	Can 3
Raritan Fire-Clays	8. Wright Dark Gray Milltown	.55	22.48	27.43	50.46	1	45	54
	7. Raritan Sand Co. Gray Piscataway	.23	.83	11.44	12.50	2	6	92
	6. Whitehead Gray Island Farm, Raritan River	2.26	6.85	28.32	37.43	6	18	76
	5. Wright Light Gray Milltown	.94	1.63	14.94	17.51	6	9	85
	4. Valentine No. Pit Gray Woodbridge	6.73	.52	13.33	20.58	32	3	65
	3. Campbell Red Clay Route 25, Metuchen	.27	1.41	20.96	22.64	1	6	93
	2. Valentine No. Pit Red Woodbridge	2.33	7.20	35.02	44.55	5	16	79
	1. Raritan Sand Co. Red Piscataway	.42	9.07	39.30	48.79	1	19	80

Thus a petrographic classification has been made, modified somewhat in stratigraphic order, to conform as far as possible with the known succession of the clay horizons as shown in the field. If the stratigraphic evidence shows that any part of this petrographic classification is incorrect, the latter arrangement should be modified to meet the proven conditions.

Some details of classification may prove of special interest, as follows:

Among the Raritan clays, No. 1 rests upon red shale and grades directly into it. No. 3, ten feet thick, also rests upon red shale. No. 2 is certainly no farther above red shale of the same sort. The gray Raritan clays Nos. 4 to 7 inclusive, lie just above the red clays. No. 8 is a dark gray clay lens in sand No. 1, ten feet above the gray clays just mentioned and is, in a sense, transitional between the Raritan and Woodbridge fire-clays.

No. 21, Edgar Brothers clay, at Milltown, is agreed by all field observers to belong in the Woodbridge fire-clay series. Petrographic classification would place it with the South Amboy fire-clays and hence it has been placed there in our chart, Plate 2. Practical experience in the use of this clay shows that its behavior is not like that of the rest of the Woodbridge clay series in general.

The gray lenticular clays in the sand pit of the Raritan Sand Company at Old Bridge, and the clays of similar appearance from the old Smith pits south of Ernston, appear to correlate with each other, both belonging to the Amboy stoneware clay series (see New Jersey Geological Survey, Clay Report 1904, page 170).

No. 35, the upper or top sandy clay of H. C. Perrine at Cheesequake, is a lenticular body in the white No. 4 sand, which overlies the Amboy stoneware clay proper; it is perhaps 50 feet below the base of the Cliffwood clay, No. 36, and is distinctly transitional between the stoneware clays and the latter clay.

The attempted correlation of the "feldspar" beds, Nos. 18, 19, and 20, brings to light some points of peculiar interest. The Valentine "Feldspar" deposit at Woodbridge is thus correlated on the basis of distribution of grain size, and also the relative proportions of tourmaline, ilmenite and zircon, with the Quigley white clay of Sayreville and the white clay lenses in sand which were lately exposed on the Sand Hills on Route 25, ten miles to the southwest. In the two relationships above mentioned these three clays differ radically from all the other clays examined and at the same time agree among themselves. The white clay of the Sand Hills is evidently a series of lenses in No. 2 sand. Whereas the clay of the old Knickerbocker pits (No. 15) along the old Lincoln Highway, two miles to the southwest of the white clay on Route 25, correlates with the Woodbridge fire-clay series, it appears that the trap rock of Rocky Hill, which is underneath the Sand Hills, was a monadnock of moderate height (100 feet or so), on the Fall Zone Peneplane, around whose base the Woodbridge fire-clay was deposited, and on whose top No. 2 sand with its white clay lenses was laid. The age of the Sand Hills deposits is thus established.

No. 26 is a clay which is about two feet thick where exposed, along Route 25, where the Lehigh Valley Railroad crosses it in Elizabeth, New Jersey, completely surrounded by reddish glacial drift of the Wisconsin epoch. The clay is seamed with limonite. It is very plastic, and in appearance and microscopic character closely resembles the Cretaceous clays herein described. Its appearance and petrographic analysis would make it seem closely similar to the Woodbridge fire-clay of the Cretaceous; but its position would appear to argue against its Cretaceous age, as it is 10 miles north of known Cretaceous exposures and has an elevation supposedly below the old Fall Zone Peneplane upon which the Cretaceous clays were deposited.

For comparison with the Cretaceous clays, a real glacial (Pleistocene) lake clay from the Hudson River at Catskill, New York, was elutriated. This shows percentages by weight as follows:

Can 1, 1.30%; can 2, 7.40%; can 3, 11.55%; Total material collected 20.25%.

This, reduced to a basis of 100%, gives 6%+37%+57% =100%. The material caught in the cans is flocculent and brownish, and the remainder which passes out with the wash water is a very fine-grained, evenly sized collection of sharp, angular ground rock dust. Thus its behavior is very different from that of the Cretaceous clays. This glacial clay shows very few heavy mineral grains, but does exhibit some of the characteristic small green tourmaline crystals which are present in all of the Cretaceous clays and are believed by the writer to have had their origin in the schists of New England.

DISTRIBUTION OF THE THREE SIZES OF GRAINS OF SANDY RESIDUES OBTAINED BY ELUTRIATION (TABLE 1)

VERTICAL DISTRIBUTION.

It is generally true that, throughout this entire series of clays, the finer material (kaolin, etc., and the smaller sand grains) greatly predominates in amount.

There was a steady increase, in general, in the amount of the *coarse* part of the sand (contents of can No. 1), as deposition progressed, from the Raritan clays at the bottom, through the Cliffwood clays to the Marls at the top, at the expense of the finer sandy material. Most of the variation in the residues is in the coarse material.

There is a general similarity in many of the samples taken from a general horizon, and in the Woodbridge clays the relations as to grain size are most nearly constant.

It does not seem possible to classify this sedimentary series by grain-size analysis, as the sediments themselves are too variable.

AREAL DISTRIBUTION OF TOTAL SANDY RESIDUE.

Definite conclusions result from graphical plotting of areal distribution of the total sandy residue; in the Woodbridge clays there is a well-defined tendency of the fine-grained sandy material to increase in relative amount toward the east, that is, away from the mainland, at such a rate that within another 20 miles east of Sayreville, the formation would probably be largely sand. A well 724 feet deep at Barren Island, L. I., shows less than 100 feet of clay in the entire section; the rest is sand.

The coarse sand grains in these clays do not increase in relative numbers toward the east, but the relative number of the smaller sand grains does greatly increase. The relative number of the medium sized sand grains is small in proportion to that of the larger and smaller sand grains, and it does not vary much in areal distribution.

QUANTITATIVE MEASUREMENT OF HEAVY MINERAL CONTENT OF THE CLAYS

The following was the method used in estimating the percentages of the three most common heavy minerals present—tourmaline, ilmenite, and zircon—in the sandy residue obtained from the clays by elutriation:

The grains were immersed in oil under a cover-glass and spread out as evenly as possible, and all of the grains of heavy minerals counted in units of equal size by use of a micrometer ocular. Grains of tourmaline, ilmenite and zircon alone were counted in this test. For example, in the elutriated products from the Cliffwood clay of Oschwald from near Keyport, the following results were obtained on one series of tests:

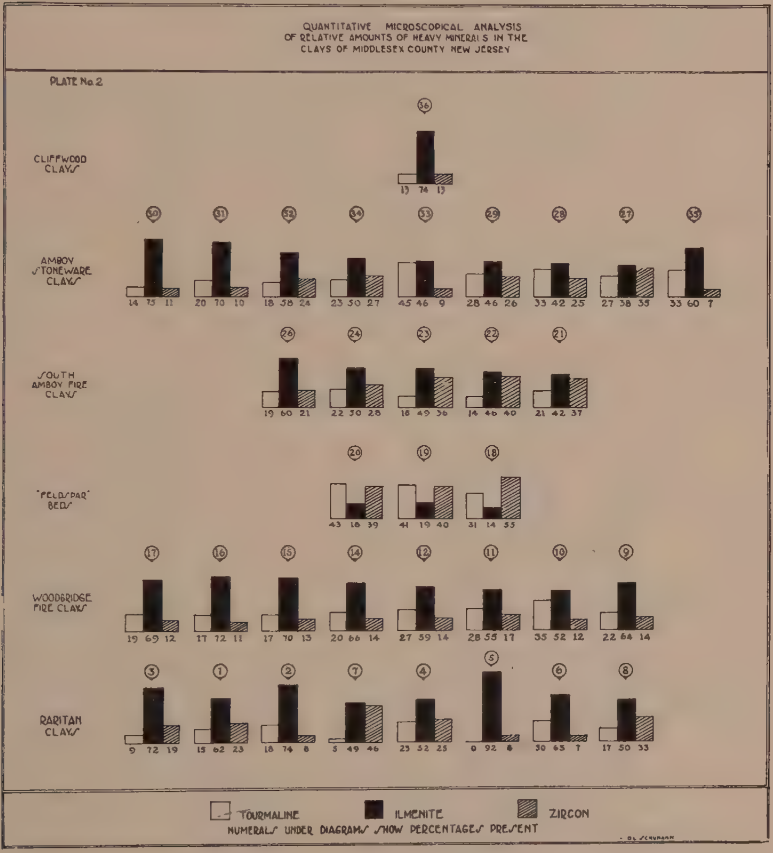

PLATE 2. Quantitative analysis of heavy minerals in clays of Middlesex Co., New Jersey.

In material from can 1, 7 units of tourmaline; 135 of ilmenite; and 12 of zircon.

This, reduced to a percentage basis, gives: tourmaline, 6%; ilmenite, 87%; zircon, 7%.

Similarly, in can 2, we find: 29% of tourmaline; 42% of ilmenite; and 9% of zircon.

In can 3 we discover, 3% of tourmaline; 88% of ilmenite; and 9% of zircon.

Then the average percentage of tourmaline in cans 1, 2, and 3, is 6+29+3% ÷3=about 13%. Similarly, the average percentage of ilmenite is 74%, and of zircon, 13%.

We thus arrive at the average percentage of these minerals in the clay, as represented in Plate 2.

Table II shows a summary of the findings in percentages of heavy minerals in the clays from various horizons.

TABLE II

PERCENTAGE OF HEAVY MINERALS IN ELUTRIATION RESIDUES FROM THE CLAYS

	Number	36	35	34	33	32	31	30	29	28	27	26	24
		%	%	%	%	%	%	%	%	%	%	%	%
TOURMALINE	Can 1	6	16	17	38	12	14	8	37	26	34	19	17
	Can 2	29	49	25	34	31	22	20	25	42	24	20	2
	Can 3	3	32	28	64	11	24	14	22	32	23	17	45
	Av.	13	33	23	45	18	20	14	23	33	27	19	22
ILMENITE	Can 1	87	68	53	54	48	74	89	44	48	33	53	33
	Can 2	48	49	50	49	41	64	55	40	26	24	55	74
	Can 3	88	64	41	33	84	73	82	54	52	58	72	43
	Av.	74	60	50	46	58	70	75	46	42	38	60	50
ZIRCON	Can 1	7	16	25	8	40	12	3	19	26	33	28	50
	Can 2	23	2	25	17	28	14	25	35	32	52	25	24
	Can 3	9	4	31	3	5	3	4	24	16	19	11	11
	Av.	13	7	27	9	24	10	11	26	25	35	21	23
	Number	23	22	21	20	19	18	17	16	15	14	12	11
TOURMALINE	Can 1	16	11	6	40	0	18	23	6	12	22	32	18
	Can 2	10	8	25	44	61	26	24	30	25	14	28	20
	Can 3	21	24	33	45	63	50	8	16	13	23	20	48
	Av.	15	14	21	43	41	31	19	17	17	20	27	28
ILMENITE	Can 1	30	42	51	20	28	18	60	88	65	52	45	70
	Can 2	70	53	25	19	8	7	68	55	60	75	68	67
	Can 3	46	42	50	15	23	16	81	73	87	72	65	27
	Av.	49	46	42	18	19	14	69	72	70	66	59	55

TABLE II (*Continued*)

PERCENTAGE OF HEAVY MINERALS IN ELUTRIATION RESIDUE FROM THE CLAYS.

ZIRCON	Can 1	54	47	43	40	77	64	17	6	23	26	23	12
	Can 2	20	39	50	37	31	67	8	15	15	11	4	13
	Can 3	33	34	17	40	14	34	11	11	0	5	15	25
	Av.	36	40	37	39	40	55	12	11	13	14	14	17
	Number	10	9	8	7	6	5	4	3	2	1		
TOURMALINE	Can 1	27	10	3	14	15	0	15	9	19	14		
	Can 2	35	31	16	0	43	0	20	8	30	30		
	Can 3	44	24	32	0	33	0	35	10	5	1		
	Av.	35	22	17	5	30	0	23	9	18	15		
ILMENITE	Can 1	65	66	65	35	85	98	61	54	64	34		
	Can 2	50	55	44	55	52	90	52	71	63	54		
	Can 3	42	72	43	56	52	88	42	90	95	99		
	Av.	52	64	50	49	63	92	52	72	74	62		
ZIRCON	Can 1	8	24	32	48	0	2	24	37	17	52		
	Can 2	15	14	40	45	5	10	28	21	7	16		
	Can 3	14	4	25	44	15	12	23	0	0	0		
	Av.	12	14	33	46	7	8	25	19	8	23		

36. Cliffwood Clay (Oschwald)
    Keyport, N. J.
35. Perrine Top Sandy Clay
    Cheesequake.
34. Perrine Gray Clay
    Cheesequake.
33. Perrine Red Mottled Clay
    Cheesequake.
32. Perrine Gray Clay
    Morgan.
31. Smith Gray Clay
    Ernston.
30. Raritan Sand Co. Gray
    Old Bridge.
29. Old Prospect Pits Red
    South Amboy
28. Old Prospect Pits Yellow
    South Amboy
27. Old Prospect Pits White
    South Amboy
26. Sayre & Fisher, Dark Gray
    West of South Amboy.
24. Sayre & Fisher, Light Gray
    Burt Creek.
23. Crossman Gray Clay
    Parlin.
22. Crossman Red Mottled Clay
    Parlin.
21. Edgar Bros. Light Gray
    Milltown.
20. Quigley White Clay
    Sayreville.
19. Valentine (Feldspar)
    Woodbridge.
18. Route 25, White Clay
    Sand Hills.
17. N. J. Clay Products Co. Gray
    South of Sayreville.
16. Natco Gray Clay
    West of South River.

15. Lincoln Highway, Gray Clay
Sand Hills.
14. Hampton Cutter Gray Clay
Woodbridge.
12. Sayre & Fisher, Gray Clay
Sayreville.
11. Natco Gray Clay
Perth Amboy.
10. McHose Bros. Gray Clay
Keasby.
9. Gray Clay in Glacial Drift
Elizabeth.
8. Wright Dark Gray Clay
Milltown.
7. Raritan Sand Co. Gray Clay
Piscataway.
6. Whitehead Gray Clay
Island Farm, Raritan River.
5. Wright Light Gray Clay
Milltown.
4. Valentine North Pit Gray Clay
Woodbridge.
3. Campbell Red Clay
Route 25, Metuchen.
2. Valentine North Pit Red Clay
Woodbridge.
1. Raritan Sand Co. Red Clay
Piscataway.

In cases where data have not been fully given in this article, the cause lies in the writer's inability to obtain material to make the figures complete, on account of the extremely small amounts of some samples obtained from the elutriation of the original 20 grams of clay.

In taking clay samples from these formations, the same general horizon has been followed as far as possible, where direct comparison was desirable; but it is impossible to follow any given stratum very far, even from one clay pit to the next, or from one side of the Raritan River to the other, because practically all of them are more or less lenticular.

It is possible to obtain figures for average content of heavy minerals in a given clay, simply by immersing a smear of it in oil or water, on a microscopic slide under a cover-glass, and counting the various sandy grains, disregarding the clay body. Incident light is used to observe the secondary limonite grains, which then appear brown, and fresh pyrite, which looks brassy. As the clays generally contain more or less lignite, which in the field of the microscope is easily confused with iron ores, it is necessary to heat all such samples to redness for a few minutes before mounting them for microscopic examination.

In this connection it is apropos to point out that from this large collection of detailed data it should be possible to work out many features of the sedimentation process which has not been thought necessary to develop in this paper. Taking, for example, the case of the Woodbridge fire-clay sample from the Sayre & Fisher pits at Sayreville:

The average amount of the three heavy minerals, compared to the quartz, in the sandy residue elutriated from the clay appears as follows: Can 1, 6.3%; can 2, 5.8%; can 3, 1.7%. The total sandy residue obtained from the clay, including the heavy minerals, is (see Table I): Can 1, 1%; can 2, 17%; can 3, 82%. This means that 1%, the coarsest part of the sandy residue, contains 6.3% of the three heavy minerals; 17%, the medium sized sand, contains 5.8%; and 82%, which is the fine-grained part of it, contains 1.7% of the smallest heavy mineral grains.

But among the heavy mineral grains counted, tourmaline amounts to 27%; ilmenite 59%; and zircon 14%, of the total of these three heavy minerals.

Also, the total sandy residue in this case amounts to 52.81% by weight of the clay.

Relative Sizes of Heavy Mineral Grains

In elutriation of these clays in the laboratory, it is found, in many cases, that most of the heavy mineral grains settle into the first or largest can, No. 1, and are much scarcer in can No. 3. This shows that a very considerable proportion of the heavy mineral grains are large. This can be explained in the case of magnetite, ilmenite, and garnet by the fact that the smaller grains readily rust to limonite, and are swept away. Other mineral grains, like those of tourmaline, may have developed as crystals of fairly uniform size in a schistose rock.

Vertical Distribution of Heavy Mineral Grains

In the Raritan clays, at the bottom of the series, results show that:

In the red clays which rest upon Triassic shale and may have been derived from the latter by replacement, the residue is quartz, with grains and "worms" of kaolin, and the heavy minerals scarcely amount to 0.1%. In the gray Raritan horizons slightly above this, can 1 shows 2.4% of heavy minerals; can 2, 2.2%; and can 3, 1.5% (sample from Woodbridge, No. 4, from the north pit of M. D. Valentine & Company).

A normal clay of the Woodbridge clay series is slightly larger in heavy mineral content; compare Natco gray clay, from the pit on west side of Perth Amboy, with can 1, 4.5%; can 2, 3.0%; and can 3, 1.0%. There is a marked concentration of heavy mineral grains in the Woodbridge series, especially near Sayreville, where the gray clay of the Sayre & Fisher Company shows: can 1, 6.3%; can 2, 5.8%; can 3, 1.7%. There is also a similar concentration shown at the property of the New Jersey Clay Products Company. Such concentration is attributable to the presence of the buried ridge of the Palisade diabase, which here closely underlies the Woodbridge clay.

The South Amboy fire-clay is often extremely sandy and much of this sand is locally largely composed of the heavy minerals; as at the Sayre & Fisher pits near Burt Creek, where can 1 shows 15.52%; can 2, 3.74%, and can 3, 1.1%.

The Amboy stoneware clay shows a great decrease in the relative abundance of heavy minerals; as in H. C. Perrine's gray clay at Cheesequake: can 1, 2.8 %; can 2, 1.0%; can 3, 0.5%. In the marls there is a rarity of heavy mineral grains, to which reference has already been made.

Details for the various clay horizons are as follows (see Pl. 2):

	Tourmaline	*Ilmenite*	*Zircon*
Cliffwood Clay	13%	74%	13%=100%
Amboy Stoneware Clay (average of 9 localities)	26	53.7	20.3
South Amboy Fire-Clay (average of 6 localities)	17.7	52.1	30.2
"Feldspar" and "Kaolin" (average of 3 localities) (Granitic)	38.3	17	44.7
Woodbridge Fire-Clay (average of 8 localities)	22.6	64	13.4
Raritan Fire-Clay (average of 8 localities)	14.7	64.3	21

a. The sample of the Cliffwood clay which was chosen, shows a vast preponderance of ilmenite over tourmaline and zircon; and the latter two minerals are exactly balanced in amount.

b. The Amboy Stoneware Clays show a preponderance of ilmenite over tourmaline and zircon in every case, but there is no fixed relation as to relative amounts of tourmaline and zircon. Irregularity appears, as in the clays in the field.

c. The South Amboy Fire-Clays show preponderance of ilmenite, while the relative amount of zircon is always larger than that of tourmaline.

d. The "feldspar" and "kaolin" series of clay lenses in sand No. 2, show ilmenite in very subordinate amount; and in this respect they are different from any of the other clays.

e. The Woodbridge Fire-Clays show a preponderance of ilmenite over tourmaline and zircon in every case; and in every case the relative amount of tourmaline exceeds that of zircon.

f. The Raritan clays at the base of the Cretaceous, lenticular and irregular, show no characteristic similarity except the usual large amount of ilmenite.

The supply of tourmaline and of ilmenite is fairly constant throughout the Cretaceous clays, ilmenite being generally far more abundant than tourmaline.

The relative amount of zircon is small in the Raritan clays, which were largely derived from shaly bed-rock. The Woodbridge clays also show a relatively small amount. The "feldspar" and "kaolin" beds above this are partly composed of coarse granitic material, and hence show an increase in zircon and tourmaline. In the clays from thence upward the relative amounts of these latter minerals decrease, probably as the schists were covered up by the encroaching margin of the clays. In the still higher marls they are very scarce. The progressive increase of zircon and tourmaline from Raritan to Woodbridge clays may be the result of erosion into the rocks containing them, or more active drainage.

Ratio of Total Percentages of The Three Heavy Minerals (Ilmenite, Tourmaline, and Zircon) to the Total Quartz in the Elutriated Residue.

This ratio varies from 20% to about 1%, in the samples studied; most of the sandy residues show a ratio of from 1% to 5%, with the marls showing a much smaller proportion of heavy minerals (about one grain of 1000 of quartz, at most). Detailed work on the contents of the various cans has been prevented by lack of material, some of the elutriated residues having been very small to begin with. Contours based on areal distribution of this relationship give definite results (see Plate 3).

Magnetite and Unaltered Feldspar in the Clays

It appears that ilmenite (nonmagnetic) is much more plentiful than magnetite, and that most of the titanium in these clays is in ilmenite, which is plentiful, rather than in rutile, which is scarce. Magnetite is present to some small extent in the Raritan Clays, and in all of the rest except in the Woodbridge series, where a mere trace was found at one locality only. This indicates conditions of shifting sedimentation.

Unaltered feldspar was not found in the Woodbridge Fire-Clay samples, but it is present in about half of the other clays observed; particularly in the Cliffwood clay. The "feldspar" beds contain it at Valentine's pit in Woodbridge only. Other correlated clays are pure white kaolin for the most part. Some of the feldspar is plagioclase, and some without twinning may be orthoclase.

DETERMINATION OF TOTAL ORGANIC CARBON CONTENT OF THE CLAYS

The carbon in these clays exists mostly as disseminated material, which gives a dark color to many of them. At other times thin filaments of carbon are found filling leaf imprints, and again it forms logs of lignite, sometimes 40 feet long and a foot or more in diameter. Pyrite often partially or wholly replaces the lignite.

Determinations of carbon were made for the writer by Mr. Meredith F. Parker, who heated the samples and measured by absorption the amount of carbon dioxide driven off. The carbon content of the various clays is as follows:

36. Oschwald, Keyport	2.72%	17. N. J. Clay Prods.	1.09%
35. Perrine, top	1.77%	16. Natco, So. River	0.83%
34. Perrine, gray	0.14%	15. Knickerbocker	0.16%
33. Perrine, red mottled	0.10%	14. H. Cutter, Wbdge.	1.30%
32. Morgan	1.16%	12. S. & F., Sayreville	1.82%
31. Smith, Ernston	0.20%	11. Natco, Perth Amboy	1.34%
30. R. S. Co. Old Bridge	3.63%	10. McHose, Keasby	1.66%
29, 28, 27. So. Amboy	0.10%	9. Elizabeth	1.06%
26. S. & F., So. Amboy	1.27%	8. Wright, dk. gray	0.89%
24. S. & F., Burt Creek	1.56%	7. Piscataway, gray	0.13%
23. Crossman, Parlin	3.29%	6. Island Farm, gray	2.12%
22. Crossman, red mottled	0.15%	5. Wright, gray	0.23%
21. Edgar gray	1.86%	4. Valentine, gray	0.15%
20. Quigley, white	0.10%	3. Campbell, red	0.05%
19. Valentine "spar"	0.07%	2. Valentine, red	0.13%
18. Sand Hills, white	0.06%	1. Piscataway, red	0.09%

AREAL DISTRIBUTION OF HEAVY MINERALS AND OF CARBON IN THE CLAYS

Plate 3 shows by means of contour lines, based upon percentages, that there is a regularity in the distribution of the heavy minerals and of total organic carbon content in the clays.

Fig. A shows that a relatively large amount of ilmenite, in small grains, was swept far out from the source of supply. In Fig. B we see that a relatively large amount of tourmaline was left near the mainland. Similar areal plotting of the zircon content also shows the same kind of distribution. The shapes of the ilmenite grains are angular and irregular. The tourmalines are perfectly formed prismatic crystals, which would roll for considerable distances very readily. Most of the zircon grains are not in the form of complete crystals, but in rounded or even spherical grains of small size;

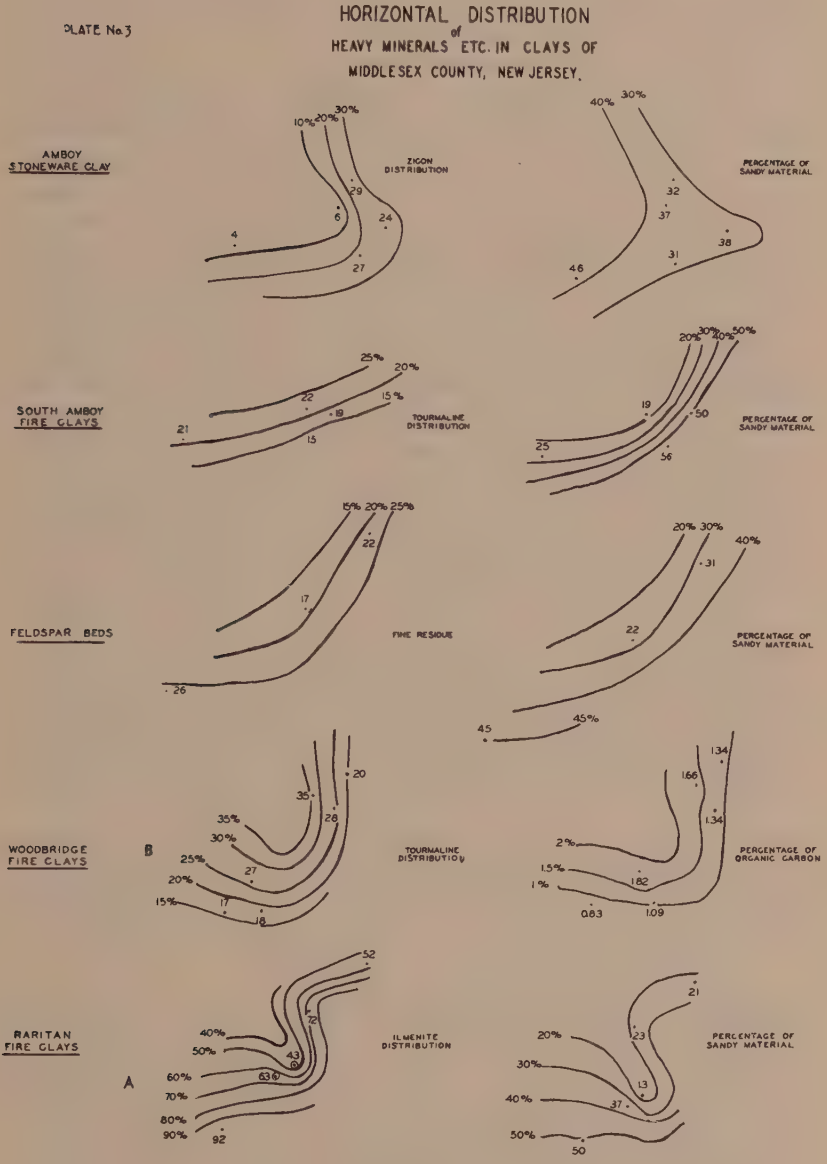
PLATE No. 3
HORIZONTAL DISTRIBUTION of HEAVY MINERALS ETC. IN CLAYS OF MIDDLESEX COUNTY, NEW JERSEY.
AMBOY STONEWARE CLAY
ZICON DISTRIBUTION
PERCENTAGE OF SANDY MATERIAL
SOUTH AMBOY FIRE CLAYS
TOURMALINE DISTRIBUTION
PERCENTAGE OF SANDY MATERIAL
FELDSPAR BEDS
FINE RESIDUE
PERCENTAGE OF SANDY MATERIAL
WOODBRIDGE FIRE CLAYS
B
TOURMALINE DISTRIBUTION
PERCENTAGE OF ORGANIC CARBON
RARITAN FIRE CLAYS
A
ILMENITE DISTRIBUTION
PERCENTAGE OF SANDY MATERIAL
10% 20% 30%
40% 30%
25% 20% 15%
20% 30% 40% 50%
15% 20% 25%
20% 30% 40% 45%
35% 30% 25% 20% 15%
2% 1.5% 1%
40% 50% 60% 70% 80% 90%
20% 30% 40% 50%

PLATE 3.

this shape is not due to attrition, but to the original poor development of the crystals which were formed, as seen today in the Manhattan schist and similar rocks.

The direction of water flow which distributed the material of these clays was plainly from the northwest, coming from the general direction of Plainfield, and spreading them outward fan-like, over the estuary of the present Raritan River. A survey of the percentages shown will disclose that extrapolation will carry them to a distance of perhaps 10 miles, to the northwest or southeast, where the various quantities will usually become 100% or 0%. Perhaps this is too uncertain to be seriously considered; but it has been found true in practically all cases, and may indicate that the vicinity of the Watchung ridges was the inner margin of deposition of this series of Cretaceous clays. This would in no way limit the much greater extent of the Marl series, deposited at later times. Perhaps the application of methods, similar to these, upon the marls might disclose the truth as to their former extent. This work the writer has begun but has not in any measure completed. It is difficult to work with the marls on account of the small number of grains of heavy minerals in them.

The clays exposed at Gay Head, Martha's Vineyard, Massachusetts, which are white, red, yellow, brown, and dark gray, show every indication of belonging to this same Upper Cretaceous series, and they have the same heavy minerals of the same typical appearance. They are very sandy; and considering their known distance above bed-rock, in the writer's opinion they may well be at the general horizon of the South Amboy fire-clays.

SPECIAL INVESTIGATION OF THE MINERAL CONTENT OF THE CLAYS

Considering the very refractory nature of the fire-clays, some little attention was paid to the presence of fluxing minerals, and the quantities of them which might be present.

Muscovite is visible under the microscope, in the fire-clay from Hampton Cutter's pit at Woodbridge to the extent of 6.3%, there being 93.7% of other minerals, in the elutriated residue in can No. 3. In the Sayre & Fisher pit at Sayreville the amount of muscovite in the corresponding can is 10.6%, and in the stoneware clay of H. C. Perrine, Cheesequake, 7.3%, for can No. 3. It is evident that there is a quantity of fine-grained mica which must have escaped with the clay body which was washed away; so these figures undoubtedly are low. At the same time, areal counts may overestimate the importance of the mica plates, which are thin and flat.

Many of these clays originally contained gypsum, which appears in tiny sheaf-like crystal aggregates; but all of it has changed by pseudomorphism to a kaolin mineral of composition precisely unknown, similar to beidellite or nontronite, and apparently intermediate between them.

Attempts to check the amounts of the oxides of boron, titanium, and zirconium were unsatisfactory. In the Valentine gray clay of the Raritan at Woodbridge, according to the heavy mineral content, $TiO_2=0.35\%$, $ZrO_2=0.215\%$, and $B_2O_3=0.00029\%$. On the corresponding gray Raritan clay at Piscataway, we find that $TiO_2=0.20\%$, $ZrO_2=0.24\%$, and $B_2O_3=.004\%$. This is in general about half as much as the analyses from reputable chemical laboratories show; so it is apparent that about half of the material containing these compounds is so fine-grained that it has been washed away with the clay.

Acknowledgement is hereby made to Professor George H. Brown for his cooperation in the work which enabled this research problem to be investigated.

BIBLIOGRAPHY

1. Passaic Folio, *U. S. G. S.*, discussion of the Cretaceous Clays, statement therein by Dr. Benjamin L. Miller.
2. *Geological Survey of New Jersey*, Report of the State Geologist, vol. **6**, 1904. The Clay Industry.
3. Heavy Minerals of the Coastal Plain of Maryland, Lincoln Dryden: *Am. Mineral.*, vol. **17**, No. 11, pp. 518–521, 1932.
4. Microscopic Minerals of the Clays of Middlesex County, New Jersey, A. C. Hawkins, A. Stollman, and L. A. Buck: *Am. Mineral.*, vol. **18**, No. 4, pp. 160–166, 1933.

TOPAZ FROM DEVIL'S HEAD, COLORADO

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With field notes by Arthur Montgomery and Edwin Over, Jr.

Abstract

Renewed operations in the pegmatites of Devil's Head, in the Pike's Peak region, have yielded a suite of noteworthy crystals of topaz associated with quartz, microcline, albite, fluorite and cassiterite. The collection includes some topaz crystals of outstanding size and regular development and many smaller crystals of unusually distorted habits. The forms observed are: *c*(001), *b*(010), *g*(130), *l*(120), *m*(110), *X*(023), *f*(011), *y*(021), *h*(103), *d*(101), *i*(113), *u*(112,) *o*(111), *r*(121), on the preferred parameters of Kokscharov. One crystal shows alteration to a mineral of the kaolin group, and they all exhibit corrosion effects, some of which are suitable for geometrical description.

In the summer of 1934 Montgomery and Over resumed field operations in the Pike's Peak region of Colorado and succeeded in uncovering a suite of topaz crystals which are superior to any obtained hitherto from this locality. A selection of the best crystals, together with specimens of the associated minerals, was acquired by the Harvard Mineralogical Museum and entrusted to the first-named author for description. The material was obtained from Devil's Head in the extreme east of the Pike's Peak region.[1] The locality was described in an early paper by Whitman Cross and W. F. Hillebrand,[2] the occurrence of topaz at Devil's Head being particularly noted in an appendix by W. B. Smith.[3] The new material and its associations conform in their main features with the above descriptions; the present paper is therefore concerned mainly with the novel features displayed by the newly found crystals.

The topaz was found in whole crystals and crystal fragments associated with quartz, microcline, albite, muscovite, rare fluorite and very rare cassiterite in pockets in pegmatite. The pockets, the largest of which is about 1×2×4 feet in size (figure 1), are numerous in a zone of the pegmatite some 3 or 5 feet deep and of undetermined extent. The coarsely crystallized pegmatite merges into a narrow zone of graphic granite in the vicinity of the pockets and then spreads into the coarse quartz and microcline of the pocket walls, where frozen masses of feldspar are in some cases nearly a foot in diameter. Within the pockets the microcline masses reach 6 or 8 inches in greatest dimension; well-formed crystals are relatively rare and they do not exceed a size of two inches. Quartz occurs in smoky crystals, in most cases slender and distorted and in some cases coated with minute crystals of hematite. In the material available for study cassiterite is represented in two imperfect crystals, 3/4 and 1/2 inch in size, with large faces of *s*(111) and narrow faces of *e*(101). Fluorite is present as a bleached and crumbly pea-sized octahedron with small rough faces of the cube.

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[1] Devil's Head (9348 feet) lies in 39°16′ N., 105°06′ W., on the topographic sheet "Platte Canyon," 1:125,000, *U.S.G.S.*, **1893**.

[2] Minerals from the neighborhood of Pike's Peak, *U.S.G.S.*, Bull. **20**, pp. 40–73, 1885.

[3] Appendix: Notes upon the occurrence of Topaz at Devil's Head mountain, *U.S.G.S.*, Bull. **20**, pp. 73–74, 1885.

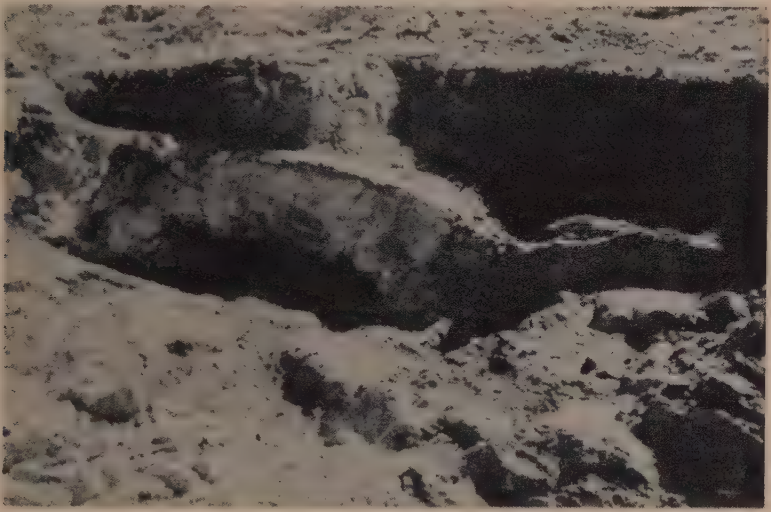

Fig. 1. One of the largest pockets, 1 foot high, 2 feet deep and 4 feet wide, in the pegmatite of Devil's Head, Colorado.

The crystals and fragments of topaz range from fist-size downward. The best-formed crystals were found loose or weakly cemented in a ferruginous mud or sand that covers the bottoms of many of the pockets. The mud contains solid ferruginous masses up to 2 lbs. in weight, and it is noteworthy that the pockets especially rich in iron are poor in topaz. The sandy pocket material appears to be derived from the albite. Distorted topaz crystals occur tightly wedged between crystals of quartz and masses of albite. Shapeless masses of reddish, opaque and somewhat altered topaz occur in the solid pegmatite adjoining the pockets both above and below. The detached and shattered condition of many of the topaz crystals and the bent and broken state of the mica in the solid pegmatite point to mechanical disturbance of the pegmatite subsequent to the formation of the pocket minerals. The corroded and altered condition of many of the topaz crystals, extending to cleaved and fractured surfaces, and the abundant infiltration of iron oxide into the pockets, indicates the action of travelling solutions after the period of crystal disturbance.

The selected material comprises six well-developed topaz crystals of considerable size, a dozen variously distorted smaller crystals, a portion of a large crystal, and a large rough crystal partly replaced by some other substance. Most of the unaltered crystals are stained pale red, mainly on the surface and along cleavage cracks; internally they are nearly colorless and transparent and only slightly flawed by basal cleavage cracks and other fractures. A few smaller crystals, later added to the collection, are perfectly colorless, giving flawless cut stones. The crystals permit good contact measurements by means of which the following forms were determined:

c (001)
b (010) g(130) l(120) m(110)
X(023) f(011) y(021)
h (103) d(101)
i (113) u(112) o(111) r(121)

All the forms are well known on topaz; they were determined by several readings on each form in good agreement with the calculated angles[4] given below:

$bg=32°14\frac{1}{2}'$ $cX=32°27'$ $ch=31°02'$ $ci=34°14'$ $cr=69°09\frac{1}{2}'$
$bl=43\ 25$ $cf=43\ 39$ $cd=61\ 00\frac{1}{2}$ $cu=45\ 35\frac{1}{2}$ $yr=39\ 57\frac{1}{2}$
$bm=62\ 03\frac{1}{2}$ $cy=62\ 20$ $co=63\ 54$ $dr=42\ 45\frac{1}{2}$

The symbols and angles given correspond to the orthorhombic elements of Kokscharov,[5] $a:b:c=0.5285:1:0.9540$, in modern conventional form. Kokscharov's orientation, adopted by Goldschmidt[6] in his numerous studies on topaz, leads to completely satisfactory correspondence between the relative importance of the forms and the relative simplicity of their indices (figure 2).

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[4] Extracted from Goldschmidt's *Winkeltabellen*, 1897.

[5] *Materialien zur Mineralogie Russlands*, **II**, p. 198, 1854–57.

[6] *Beitr. Kryst. Min.*, **III**, p. 172, footnote 3, 1934.

Dana[7] adopted another setting which is related to that of Kokscharov as follows:

$$a:b:c \text{ (Dana)} = a:b:\tfrac{1}{2}c \text{ (Kokscharov)}$$
$$h\ k\ l \text{ (Dana)} = 2h\ 2k\ l \text{ (Kokscharov)}$$

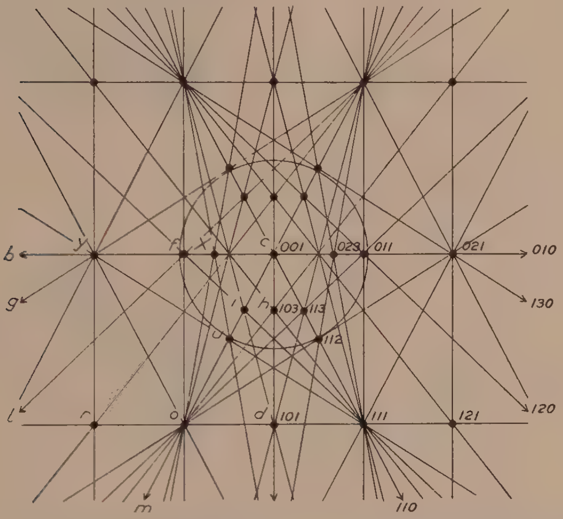

FIG. 2. Topaz. Gnomonic projection of the forms found on the crystals from Devil's Head. Observe the subhexagonal pattern and the importance of the poles of *o*(111), the preferred unit form, as zonal nodes.

Forms: *c*(001), *b*(010), *g*(130), *l*(120), *m*(110), *X*(023), *f*(011), *y*(021), *h*(103), *d*(101), *i*(113), *u*(112), *o*(111), *r*(121).

In this setting the symbols of the principal forms are relatively less simple and some rare forms receive the simplest indices. It is interesting to note that the ratio of the cell sides of topaz, determined röntgenographically by Alston and West,[8] agrees with Kokscharov's elements to the fourth place of decimals.

The selected crystals, grouped under five types according to the development of the prism zone, show the following combinations of forms:

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[7] *System.* 6th ed. **1892.**

[8] *Zeit Kryst.*, vol. **69**, p. 150, 1928.

Type	Crystal	Combination
I	1	*c . g l m X f y . d i u o .*
	2	*c b g l m X f y h d i u o .*
	3	*c b . l m X f y h d . u o .*
	4	*. . . l m X f . h d . u o .*
	5	*c . . l m X f y . . . u o .*
	6	*c b g l m X f y h d i u o r*
	7	*. . . l m . f y . . i . o .*
	8	*. b . l m . f y . d . . o .*
	9	*. . . l m . f y . . . . o .*
II	10	*. . . . m . . y . d i . o .*
	11	*. . g l m X f y . . . . o .*
	12	*. . . l m . . y . d . . o .*
III	13	*. b g l m . f y . . i . o .*
	14	*. b . l . . . y . d . u o .*
IV	15	*. b g l m . f y . d . . o .*
V	16	*c b . l m X . y . d i . . .*
	17	*. . . l m . f y . . . . o .*
	18	*. . . l m . f y . d . . o .*
	19	*. . . l m . f y . d i u o .*

Type I. The crystals of this type have a stout columnar habit due to like development of the pseudo-hexagonal prism *m* and the pseudo-tetragonal prism *l*. Crystal 1 (figure 3) is the largest in the collection and probably the largest well-formed and well-preserved topaz crystal found in North America.[9] It measures 8.2×11.0×8.0 cm. in the directions of the axes, *a*, *b*, *c*, respectively, and weighs 1160 gm. All the forms are represented by good faces except the base *c* and the brachydome *X*. The latter is formed in reality by the summits of small, close-set corrosion residuals which evidently represent *X* rather than the steeper brachydome *f*. This appears from the fact that the faces of the low pyramid *i* are certainly not corrosion faces, which they would be had *X* developed by corrosion of *f*. The base *c*, although rough, is then also a true form.

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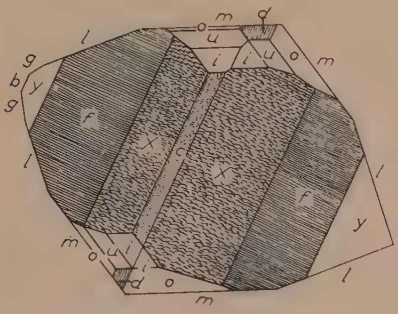
[9] Cavernous ruins of much larger topaz crystals, resulting from far advanced solution, have been described from Topsham, Maine, by Palache, *Am. Jour. Sci.*, vol. **27**, p. 37, 1934.



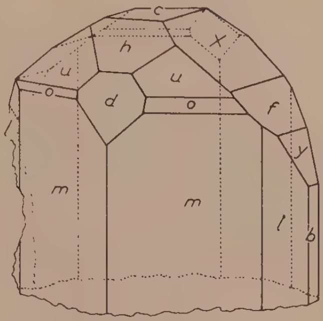
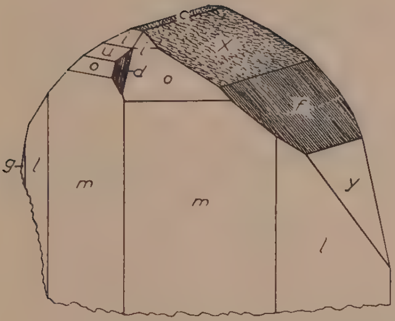


FIG. 4. Type I, Crystal 3.



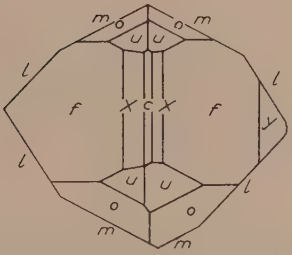


FIG. 3. Type I, Crystal 1, showing the characteristic etch effects on *c*, *X*, *f*, *d*.

FIG. 5. Type I, Crystal 5.

Crystal 2 measures 5.6×7.5×5.8 cm.; it is similar to crystal 1 and likewise an outstanding specimen. Crystal 3 (figure 4), 3.3×4.3×3.9 cm., is remarkable for the relatively large development of a face of the macrodome *h*. Crystal 4 measures 3.6×4.8×4.1 cm. and resembles crystal 3. Crystal 5 (figure 5), 3.3×4.1×6.0 cm., is a tall, well-formed specimen of relatively simple development. Crystal 6 (figure 6) is an unequally developed example measuring 2.8×4.5×4.8 cm.; it is the only specimen showing all the forms and the only one with the pyramid *r*. These six crystals are the finest in the collection.

The remaining crystals range from 4.3 cm. in the greatest dimension to 0.4 in the least. For the most part they lack the regularity

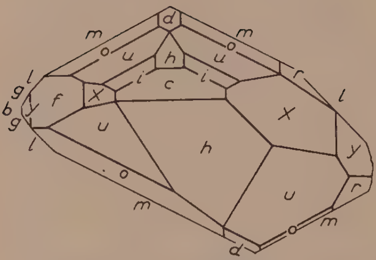


FIG. 6. Type I, Crystal 6, showing all the forms observed at this locality.

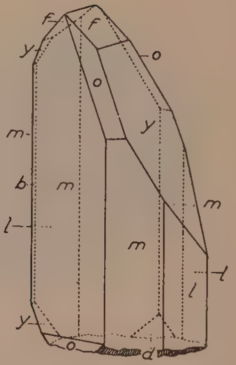


FIG. 7. Type I, Crystal 8.

and quality of the larger crystals and show unusual inequalities of development. Three of these may be classed with Type I: crystal 7 is a simple incomplete example; crystal 8 (figure 7) is cut aslant by a large face of the brachydome *y*; crystal 9 is terminated at both ends mainly by badly corroded faces of the same form.

TYPE II. In this type the prism zone is dominated by *m*. In crystal 10 (figure 8) the development is fairly regular; crystal 11 shows marked flattening with *m;* crystal 12 has *o* and *d* on both terminations.

TYPE III. The appearance of these crystals is controlled by the development of the prism *l*. Crystal 13 (figure 9) is strongly flattened with *l* and doubly terminated; crystal 14 is similar.

TYPE IV. A single specimen, crystal 15 (figure 10) is strongly flattened with the prism *g*, which on other crystals is only an insignificant form.

TYPE V. The four remaining crystals are mainly combinations of domes and pyramids with subordinate prismatic forms. In crystal 16 (figure 11) a relatively large base is combined with the nearly hexagonally arranged faces of the brachydome *X* and the pyramid *i*. Crystal 17 is a parallel growth of two short irregular individuals with remnants of double terminations. Crystal 18 has *d* and *o* above and below. Crystal 19 combines a large base below with domes and pyramids above, giving the hemimorphic appearance occasionally observed on topaz.[10]

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[10] Adams and Graham, *Trans. Roy. Soc. Canada*, vol. **XX,** sec. 4, p. 134, 1926. Alston and West, *Zeit. Kryst.*, **69,** p. 149, 1928, assigned the structure of Nigerian topaz to the holohedral class of the orthorhombic system.

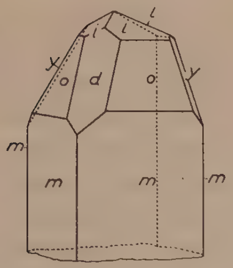

FIG. 8. Type II, Crystal 10.

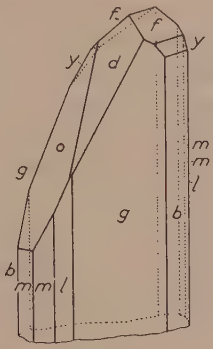

FIG. 10. Type IV, Crystal 15.

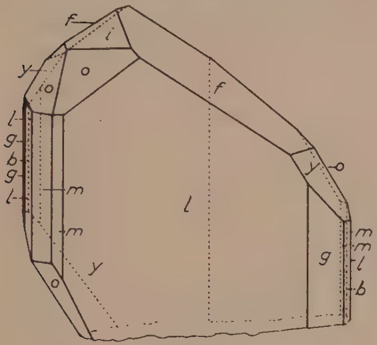

FIG. 9. Type III, Crystal 13.

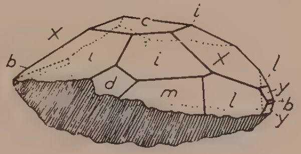

FIG. 11. Type V, Crystal 16.

The etching on these topaz crystals shows some interesting features. As is usually the case, different forms have offered unlike resistance to corrosion: generally the base and the terminal forms with smaller polar distances have suffered most while the forms with greater polar distances have best withstood the attack of the corroding fluids. This is also true of the doubly terminated crystals, showing that the selective corrosion is due not to unequal exposure to attack but to unequal resistance of planes in different directions through the crystal structure.

The brachydome zone [*c b*] shows strong and characteristic corrosion which is present on all the crystals and aids considerably in orientating the distorted examples. The base *c* is strongly pitted, in some cases with regular lozenge-shaped etch pits whose longer and shorter diagonals are parallel to the corresponding crystal axes. The pits are 0.5 to 1.0 mm. long and each is lined by a somewhat rounded negative pyramid from which a reflection was not obtained. The azimuth of this corrosion form is given, however, by the angle of lozenge which was measured on a photograph on *c* taken with the axis of the camera parallel to the *c*-axis. The azimuth angle was thus found to be 68°, from which it follows that the corrosion pyramid has a complex symbol of the form 43*l*.

The most striking etch effects on the crystals are the beautifully formed corrosion knobs on the brachydome *X*. The surface of *X* is composed wholly of these sub-hexagonal shield-shaped bodies lying, with much mutual interference, with their long axes in the plane of 100. Crystal 3 was mounted on the two-circle goniometer, adjusted by means of reflections from thin glass plates stuck on adjacent prism faces, and the form of a typical corrosion knob on *X* was determined by measuring and plotting the interrupted trains of reflections from its brilliant but curved surfaces. Figure 12 gives a plan of the corrosion knob, which is about a millimeter long, and the gnomonic projection of the reflection trains. The projection conforms to the orthorhombic symmetry of topaz, and some points on the trains approach simple rational positions. But it is evident that the corrosion form is mainly bounded by facets with highly complex symbols.

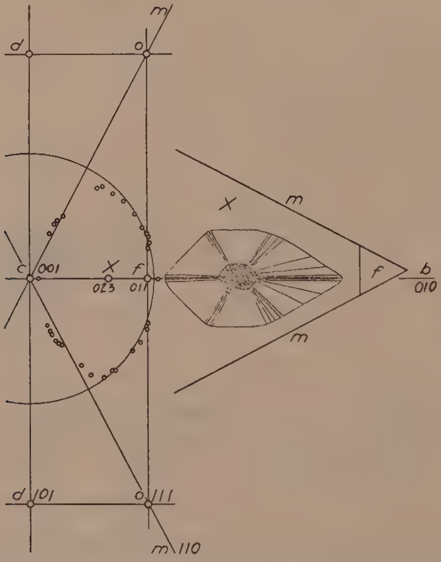

Fig. 12. Plan and gnomonic projection of a corrosion knob on *X*(023).

On the brachydome *f* the same etching that produced the etch knobs on *X* gives parallel furrows lying in the plane of (100). At the junction of *f* and *y* these furrows cease abruptly and give place to slight pitting on the steeper and relatively resistant plane *y*.

In the macrodome zone *h* is frequently marred by small sparse etch knobs. The edge between *h* and *d* is rounded with the formation of minute residual projections, and *d* is marked by fine, acutely downward tapering ridges lying in the plane of (010). The forms in the pyramid zone are variously marked with delicate patterns in which it is difficult to detect any significant regularity. The forms in the prism zone are mostly free from etch effects. The narrow brachypinacoid *b* is sometimes faintly marked by light striae lying in the plane of (001); the unit prism *m* is marked in some cases by feeble growth vicinals and occasionally etched with a rectangular panelled pattern.

These few observations on corrosion effects on topaz are in accord with the usual conclusion that corrosion forms conform to the symmetry of the crystal, although the component faces of such forms have complex symbols even when they give good reflections. It is probable that many of the complex symbols in the crystallographic literature are based on reflections from etched surfaces. If this were more constantly kept in mind, further additions of insignificant symbols to crystallographic form lists would be restrained.

In a study on the forms and accessories[11] of topaz, Goldschmidt[12] described several crystals from Florissant, which is in the Pike's Peak region of Colorado. While there is a general similarity between our crystals and those described by Goldschmidt, the corrosion forms on *X*(023) observed on the Devil's Head material have no counterpart in Goldschmidt's stereographic projections of the accessories on the Florissant crystals. This is no doubt due to differences in the solution conditions which are known to produce different solution forms on crystals of the same species.

It remains to mention the alteration product which has partly replaced one large rough topaz crystal in the collection. The material appears in nests of minute radially arranged white fibres or plates with pearly lustre. On this substance Mr. Berman observed a mean refractive index of 1.565, weak birefringence and positive elongation. These characters indicate a member of the kaolin group.

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[11] An apt term proposed by Goldschmidt to distinguish all solution forms and vicinal growth forms from normal plane-faced growth forms. The latter are the only forms properly entitled to symbols and a place in a form list.

[12] *Zeit. Krist.*, vol. **40**, p. 380, 1905.

THE MICROPYCNOMETRIC METHOD FOR THE DETERMINATION OF SPECIFIC GRAVITIES OF MINERALS

F. V. Syromyatnikov, *Moscow, U.S.S.R.*

Modern methods for the determination of minerals aim to reduce the quantity of material tested to that minimum which is considered necessary for a positive identification. On the one hand, optically, due to the immersion method, it is possible to determine the indices of refraction of mineral grains, the size of which need not exceed that of a pin head. Microchemical tests also permit the application of a whole series of chemical reactions on an extremely small quantity of material. The use of the blowpipe supplements these various methods of determination. In a number of cases, however, all these methods prove insufficient, and the determinations of hardness and specific gravity are necessary. The first of these is usually measured only approximately; hence the second property frequently plays the decisive role.

The determination of specific gravity of small fragments of a mineral can be accomplished easily by the well known method of mixing two liquids until the specific gravity of the mixture equals that of the mineral. Due to the absence, however, of liquids with a high specific gravity this method is practicable only when the specific gravity is less than that of methylene iodide (3.3), or Thoulet solution (3.2), or Clerici liquid (4.5). In as much as the latter is very expensive, highly poisonous and difficult to obtain, the practical limit is therefore 3.3. Thus the problem of extreme interest is the development of a method for determining the specific gravity of minerals in cases where it exceeds 3.3, using the minimum quantity of material possible. For this purpose a new method, conventionally termed *the micropycnometric method*, has been suggested by the author.

For the determination of the specific gravity of mineral grains a number of methods have been suggested.[1] Some authors use the hydrostatic method, thus increasing the delicacy of weighing over that of the Jolly or the torsion balance. Others make use of the method of immersing the mineral grain in some liquid medium, observing the velocity of its descent in heavy liquids or varying the specific gravity of the liquid within the limits required. From the author's point of view the latter method is more satisfactory with regard to both speed and the accuracy of the determination (±0.01). It is to be regretted that this method, as mentioned above, has found but limited application.

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[1] Rosenbusch, H., Mikroskopische Physiographie, Bd. 1, 1 hälfte, S. 671.

Although, according the Spencer,[2] minerals with a specific gravity of 2.75 are the most abundant, a whole series of common rock-minerals (hornblende, tourmaline and others), also sulphides, have a specific gravity above the limit indicated. The determination of minerals of friable sedimentary rocks, such as the "heavy" minerals in sands urgently calls for the need of determining specific gravities exceeding the figure three.

Many attempts have been made to extend the application of the immersion method by causing a small fragment of a heavy mineral to adhere to objects having a low specific gravity. In determining the specific gravity of such a system by the ordinary method, the specific gravity of a mineral is comparatively easy to obtain.

A very ingenious method was that described by Retgers,[3] who used glass pincers for picking out mineral grains. Sommerfeld[4] replaced them by an aluminium wire, which is not applicable with liquids of the Thoulet type. This method, called the suspension method, is of special interest to us as it competes with the method described later. We shall, therefore, dwell upon it at some length. Its defect in principle is due to the indirect method of determining the constant. Its drawback in practice is the large surface of the system and the possibility of adhering air bubbles.

Retgers and Rosenbusch have made a study of the errors involved in the method. The accuracy in weighing is of the greatest importance in the determination of the specific gravity of a mineral. The quantity of the material tested also plays an important role, which is well illustrated by the following table 1.

TABLE 1

Volume of the mineral	Specific gravity	Absolute error	Relative error
0.05 cm^3	4.4	0.002	0.05%
0.005 "	4.4	0.022	0.50%

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[2] *Mineral. Mag.*, vol. **XXI,** pp. 337–365, 1927.

[3] *Zeits. f. phys. Chem.*, vol. **4,** pp. 190–196, 1889.

[4] *Zentrabl. f. Mineral.* p. 482, 1910.

The effect of the size of the float is also noteworthy; it is therefore recommended by the author that a definite correlation be maintained between the quantity of the mineral and the size of the float.

As the result of all these factors, the following limits of error may be established:

TABLE 2

The quantity of mineral weighed	Specific gravity	Accuracy of weighing	Absolute error	Relative error
0.170 gram	4.01	±0.0001	±0.013	0.3%
0.170 gram	4.01	±0.00005	±0.007	0.17%

These figures apply when the specific gravity of a liquid or mixture is determined with an accuracy of from ±0.001 to ±0.0005. According to Rosenbusch this exactness does not present any special difficulty.

Summing up what has been said we can state that the suspension method of determining the specific gravity of a mineral when the weight is about 0.2 gram is about one tenth of a per cent, provided the weighing be precise.

Considering the method from the standpoint of actual practice it is necessary first of all to point out the fact that the use of a float is impossible in cases where the mineral is in the form of small grains, and such is frequently the case. Further, such precision in weighing and determining the specific gravity of a liquid is rather time consuming. In the author's opinion such exactness in determining the specific gravity of a mixture of liquids cannot be attained, due to changes of temperature with consequent changes in composition as the light component undergoes slight volatilization. Therefore, the actual accuracy of the suspension method is lower than that indicated by its authors. Finally, mention should be made of the fact that an increase in the specific gravity of a mineral still further reduces the accuracy.

It is well known that the pycnometric method of determining specific gravity is the most precise of all existing methods. Consequently, it was natural to attempt to apply it to the case of small quantities of weighed material. A study of the errors of the pycnometric method[5] brings us to the conclusion that it is necessary to bring the volume of the quantity weighed as near as possible to that of the pycnometer.

The ideal case for the mineralogist and the petrographer would be to measure the specific gravity of one small grain of the mineral, i.e., with a volume of about 1 cubic mm. In practice, however, it is nearly always possible, with few exceptions, to have about ten such grains, or a single fragment with an equivalent volume. That is why we have assumed a volume of 10 cubic mm. = 0.01 cc. as most suitable.

Further, the question arose as to the size and shape of the pycnometer. We have proposed the use of a simple glass tube with one end closed, while on the other end a line was drawn at the beginning of the test in order to establish the meniscus. The volume of the liquid was about 0.07 cc.

The first tests with garnet showed the general adaptability of the method. With the quantity of material equal to 0.04 gram and with the specific gravity of about 4, this gives the required volume of 0.01 cc., and the error of a particular determination will not exceed ±0.04. With especially careful work the accuracy of ±0.01 was attained. The weak point was found in the difficulty of establishing the level in the same place. Here considerable liberty was left to the personal equation of the observer. We have eliminated this defect by applying a polished glass plate to the edges of the tube (see fig. 1). After the pycnometer had been filled with the liquid, the cover was applied, the excess of liquid was removed, and the pycnometer was weighed by the extrapolation method. Proceeding thus in determining the volume of the pycnometer a precision of a few units in the fifth decimal place was attained, while formerly the variations had been of the order of ±0.01 cc. Moreover, this method afforded the possibility of reducing the time required for the determination. We have called this procedure the "micropycnometric" method. Further improvements will, no doubt, fully justify this name.

The sequence of the method is briefly as follows:

(1) The determination of the volume of the micropycnometer. After being washed with alcohol, dried and weighed on a delicate balance, the pycnometer is filled with a liquid. We have used bro-

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[5] В. Карандеев и А. Ферсман, О погрешностях при определении уд.веса твердых тел пикнометром. 1914г. стр. 5.

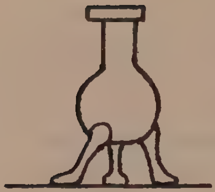

Fig. 1.

moform, the high specific gravity of which permits of a more accurate measurement of the volume. The most convenient way of filling is by means of a capillary tube. Keeping the pycnometer in a vacuum for 20–30 minutes frees the liquid from air bubbles. Then the cover is applied in such a way as to remove any excess of liquid.

As soon as the excess of liquid has been removed by means of a filter paper, the stopwatch is started, and the micropycnometer is weighed by the extrapolation method.

Our observations have shown a velocity for the fall of a weight of 0.0001 gram to be 75 seconds. To obtain the constant it is necessary to make this determination several times.

(2) A quantity of the weighed mineral is placed in a clean, dry micropycnometer. The filling of the pycnometer with bromoform[6] comes next, which is followed by freeing the pycnometer from air bubbles in a vacuum. The whole process does not take more than 2 hours.

The specific gravity is determined with the aid of the well known simple formula:

$$\lambda = \frac{W_2 - d}{W_1 + W_2 - W_3}$$

where

W_1 is the weight of bromoform in the micropycnometer.
W_2 is the weight of the mineral.
W_3 is the weight of bromoform+the mineral.
d is the specific gravity of the bromoform.

An analysis of this formula shows the following:

The error of determination will be equal to:[7]

$$d\lambda = \Delta w \cdot \frac{\lambda}{d} \cdot \frac{W_2 - W_3}{w_2^2} + \Delta d \cdot \frac{\lambda}{d}, \tag{1}$$

where

$$d\lambda,\ \Delta w \text{ and } \Delta d$$

are the corresponding errors of the measurements λ, w and d. Under the conditions of our test λ has twice, and rarely three times, the value of d. Therefore, the second member of the formula must play an insignificant part, for Δd usually does not exceed ± 0.001. The error of weighing is ± 0.0001. With the use of a microchemical balance it can be still further reduced. Its coefficient, however, may be rather large. The quantity of the mineral weighed under our conditions is always a small fraction, consequently the raising to the second power will considerably increase the magnitude of the error. In the numerator we have the difference $W_2 - W_3$, which is also a fraction. The smaller it is, the less will be the influence of the quantity of the mineral weighed and the smaller the error of the measurement.

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[6] Another liquid may be used.

[7] This expression is obtained in the usual way according to the formula: $d\lambda = \Delta w\ \partial\lambda/\partial w + \Delta d\ \partial\lambda/\partial d$; the deduction is omitted.

As an example let us calculate the error of the determination of the specific gravity in the following instance:

$$\lambda = 6.0,\ d = 3.0,\ W_1 = 0.20,\ W_2 = 0.06,\ W_3 = 0.23.$$

Let us take into consideration only the first member of the formula (1).

Then we shall have:

$$d\lambda = \pm 0.0001 \cdot \frac{6}{3} \cdot \frac{0.17}{(0.06)^2} = \pm 0.009.$$

These figures show that: (1) the absolute error is near ± 0.01; (2) the increase in the specific gravity of the mineral reduces the error of its measurement.

Experience has shown that the actual errors are very close to the calculated values (see table 3).

TABLE 3

Mineral	Quantity of mineral weighed	Specific gravity	Average	Probable error of an individual determination	Calculated error
Garnet	0.0320	4.157	—	—	—
"	0.0383	4.150	4.144	±0.014	±0.014
"	0.0445	4.125	—	—	—
Lead	0.1058	11.275	—	—	—
"	0.1007	11.266	11.271	±0.006	±0.005

Hence the practical accuracy of the determination by the micropycnometric method may be assumed to be: $d = \pm 0.01$.

This is the absolute error. Accordingly, the relative error will be easily found to be equal to

$$\frac{d\lambda}{\lambda} = 0.3\%$$

or less.

Let us compare the results obtained with those of the suspension method. Previously we have seen that with 0.1700 gram of a mineral the specific gravity can be determined with a relative error also of 0.3% (with on accuracy of weighing $= \pm 0.0001$). So large a sample does not speak favorably for the suspension method. Indeed, if we took such a quantity using the micropycnometric method, we should obtain a relative error of only 0.02%, that is, more than ten times as accurate. By increasing the exactness of weighing, both methods can be made correspondingly more accurate.

As to the length of time consumed, the two methods hardly differ in any essential respect.

Summarizing we may draw the following conclusion: the micropycnometric method is a step forward both as regards accuracy and the reduction of the quantity of material tested.

Further improvements are possible in the direction of reducing the size of the micropycnometer, with regard to its shape, the accuracy of weighing and the corrections for temperature, for the error of determining the specific gravity of the liquid, etc. Every development may permit either more accurate results, or a decrease in the quantity of the material used. But even what we have obtained at present will facilitate considerably the indentification of minerals.

The development of this method was perfected in the physical and chemical departments of the Petrochemical Laboratory of the Institute of Economic Mineralogy. The determinations of specific gravities by the micropycnometric method was performed by T.J. Shashkina, a laboratory assistant in the department.

ADAMITE FROM GOLD HILL, TOOELE CO., UTAH

Lloyd W. Staples, *Stanford University, California.*

This study of adamite was made on two individual contributions of material. In November 1932, a specimen from Gold Hill, Utah, with crystals of adamite attached was sent to the mineralogical laboratory of Stanford University by Mr. S. R. Wilson. About a year later a suite of specimens from the same locality was contributed by Dr. W. R. Landwehr. This material had been collected from an outcrop on the property of the Western Utah Copper Mining Company. Adamite previously collected from this locality by Dr. Landwehr was first identified by Professor A. L. Crawford[1] of the University of Utah.

Adamite, a basic zinc arsenate [$Zn_2(OH)AsO_4$], is a member of an interesting group of minerals, commonly referred to as the olivenite group. The group includes the following members:

Olivenite	$Cu_2(OH)AsO_4$
Libethenite	$Cu_2(OH)PO_4$
Adamite	$Zn_2(OH)AsO_4$
Descloizite	$PbZn(OH)AsO_4$
Mottramite	$PbCu(OH)AsO_4$
Higginsite	$CuCa(OH)AsO_4$

Bannister[2] has indicated that there is a complete isomorphous series between descloizite and mottramite and he suggests the use of the name mottramite for all members containing more than 10% CuO.

The mineral adamite was originally described and analyzed by C. Friedel,[3] who found it accompanying silver on a specimen from Chañarcillo, Chile. The geometrical crystallography was established by Des Cloizeaux[4] on material from the same locality, obtained from the collection of M. Adam, after whom the mineral was named. In the United States, adamite was first recognized by Means,[5] in the Tintic district of Utah, while he was engaged in preliminary work in the preparation of Professional Paper 107 of the U. S. Geological Survey. It was also noted from the same district by Butler.[6] Considering the world as a whole, there have been relatively few occurrences of adamite reported. In addition to the above mentioned occurrences it has also been found at Cap Garonne near Hyères, France; Laurium, Greece; Monte Valerio, Italy; Reichenbach, Schwarzwalde; Island of Thasos, Turkey; three localities in Algeria, and it has been thought to occur at Kiura, in Bungo, Japan. The mineral has been prepared artificially by A. de Schulten[7] exhibiting the forms: {101}, {010} and {120}.

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[1] Oral communication, June 21, 1934.

[2] Bannister, F. A., *Mineralog. Mag.*, vol. **23,** pp. 376–386, 1933.

[3] Friedel, C., *Compt. Rend.*, vol. **62,** p. 692, 1866.

[4] Des Cloizeaux, A., *Compt. Rend.*, vol. **62,** p. 695, 1866.

[5] Means, A. H., *Am. Jour. Sci.*, 4th ser., vol. **41,** p. 125, 1916.

GENERAL DESCRIPTION OF THE ADAMITE.

The adamite at Gold Hill is found in the oxidized zone, lining small cavities in a gossan and sometimes coating it. The specimens examined in this study were taken from outcrops of the orebody. Associated with the adamite is an impure limonite, crystals of quartz and calcite, and the new mineral, austinite, recently described by the writer.[8]

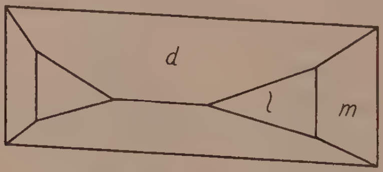

FIG. 1. Most common habit of the Gold Hill adamite showing the forms: *d*{101}, *m*{110}, and *l*{210}. Actual length of crystal is 1 mm.

The Gold Hill adamite occurs in two distinct habits, as individual, prismatic, orthorhombic crystals of the type shown in fig. 1, and in fan-shaped rosettes (fig. 2). The rosettes are nearly colorless while the individual crystals are more commonly pale honey yellow. However, the color is not sufficiently characteristic so that it always can be used with safety in distinguishing the adamite from its colorless associates. The crystals are elongated parallel to the *b*-axis and the forms present are: *d*{101}, *m*{110}, *b*{010}, *l*{210}, and *n*{120}. The luster is vitreous and the best cleavage is parallel to *d*{101}, with a poorer one parallel to *b*{010}. The average size of the crystals is 1 mm. but those that are good enough for measurements are usually only about half that size.

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[6] Butler, B. S., et al, *U. S. Geol. Survey, Prof. Paper*, **111**, p. 114, 1920.

[7] de Schulten, A., *Bull. Soc. Fran. Mineral.*, tome **26**, pp. 91–94, 1903.

[8] Staples, L. W., *Am. Mineral.*, vol. **20**, pp. 112–119, 1935.

The rosettes tend to be semi-circular and have a radius of 1 mm. Because of the difference in color and habit, it was first thought that the rosettes were not the same mineral as the individual crystals, but they were shown by microchemical tests to have the same composition and their optical properties also proved them to be adamite.

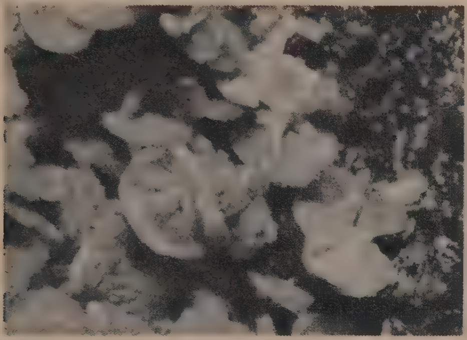

Fig. 2. Adamite occurring as rosettes. Magnification 10×.

Chemical Properties

Qualitative chemical tests were made on the material, using small amounts and microchemical methods. Both the rosettes and the individual crystals gave good tests for zinc and the arsenate radical. The test for zinc was made with potassium mercuric thiocyanate [$K_2Hg(CNS)_4$], and the arsenate radical was shown to be present both by the $AgNO_3$ and the $(NH_4)_2MoO_4$ tests. No other elements were detected so the material is thought to be quite pure. The adamite is easily soluble in cold dilute HCl and advantage was taken of this property to produce etch figures. These form in two to three minutes on the prism faces in the principal zone [101] when the mineral is placed in very dilute HCl (1:6), and they indicate rhombic dipyramidal symmetry.

Optical Properties

The indices of refraction of the Gold Hill adamite are:

$$n_\alpha = 1.711 \pm 0.003,\ n_\beta = 1.732 \pm 0.003,\ n_\gamma = 1.756 \pm 0.003.$$

They were determined with the aid of a Wratten orange screen (E 22) made by the Eastman Kodak Co. The mineral is optically positive, the plane of the optic axes is normal to $b\{010\}$, and the orientation is $a=\alpha$, $b=\gamma$, $c=\beta$. Although the crystals are usually slightly colored, the coloring is not deep enough to permit an observation of pleochroism, such as that noted in crystals from Chañarcillo by Spencer.[9]

GEOMETRICAL CRYSTALLOGRAPHY

Over a hundred crystals of adamite from Gold Hill were carefully examined on the goniometer and the best of these were selected for measurement. The results of these measurements are given in the accompanying table.

CRYSTAL MEASUREMENTS ON ADAMITE

Angle		No. of xls	No. of meas.	Limits	Aver. angle (weighted)	Calculated angle
dd'	$101\wedge\bar{1}01$	15	94	72° 5′– 72°12′	*72° 8′	
mm'''	$110\wedge1\bar{1}0$	10	24	88 21 – 88 34	*88 30	
ll'''	$210\wedge2\bar{1}0$	8	14	51 54 – 52 14	51 59	51°56′
nn'''	$120\wedge1\bar{2}0$	2	8	125 34 –125 50	125 43	125 40
mb	$110\wedge010$	8	20	45 41 – 45 48	45 44	45 45
md	$110\wedge101$	1	4	65 5 – 65 6	65 5	65 3
ld	$210\wedge101$	1	4	58 4 – 58 6	58 5	58 3

The axial ratio for the Gold Hill adamite, calculated from the angles marked with asterisks, is:

$$a:b:c=0.9742:1:0.7095.$$

The calculated angles for the unit faces are:

$$100\wedge110=44°15'; \quad 001\wedge101=36°4'; \quad 001\wedge011=35°21.'$$

There has been considerable variation in the measurements made on adamite by former investigators. The probable cause for this is a slight variation in the chemical composition, but due to the lack of complete and adequate analyses, it has been impossible to make a detailed study of this point. A tabulation of the axial ratios obtained on adamite from various localities is given below. No attempt is made to average the ratios and to compare this value with that obtained on the new material, since if the variation in values is dependent on differences in chemical composition, any value obtained by averaging would be entirely artificial and meaningless.

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[9] Spencer, L. J., *Mineralog. Mag.*, vol. **17**, pp. 114–115, 1914.

AXIAL RATIOS FOR ADAMITE

Investigator	*Locality*	*a*:*b*:*c*
Des Cloizeaux[10]	Chañarcillo	0.9733:1:0.7158
Laspeyres[11]	Laurium (1)	0.9958:1:0.7176
Laspeyres[11]	Laurium (2)	0.9958:1:0.6848
Aloisi[12]	Monte Valerio	0.9736:1:0.7013
Rosický[13]	Thasos	0.9764:1:0.7049
Ungemach[14]	Laurium	0.9770:1:0.7124
Staples	Gold Hill	0.9742:1:0.7095

A peculiarity of some of the crystals that might cause an error in angle determination may well be noted. In the case of three crystals, all of which appeared quite perfect and gave excellent reflected signals from all four faces in a prism zone, it was noted that opposite faces were not exactly 180° apart. The variation from true parallelism was the same for each pair of faces. This is mentioned to indicate the danger of obtaining incorrect values if only two of the faces in the zone were used to get the interfacial angle. To insure against this type of error, only those measurements were accepted that could be checked by signals from all the faces of any form.

A study of etch figures on the adamite crystals gave a further check on the propriety of placing it in the rhombic dipyramidal class of the orthorhombic system ($3A_2 \cdot 3P \cdot C$).

ACKNOWLEDGMENTS

The author wishes to take this opportunity to express his gratitude to Mr. S. R. Wilson and Dr. Landwehr for the material on which this study was made, to Professor A. Pabst of the University of California for use of some equipment, and to Professor A. F. Rogers for valuable suggestions and advice during the whole course of this study.

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[10] Des Cloizeaux, A., *Op. cit.*, (Axial ratio calculated by the writer from Des Cloizeaux's measurements).

[11] Laspeyres, H., *Zeit. Kryst.*, vol. **2**, pp. 147–152, 1878.

[12] Aloisi, P., *Proc. verb. d. Soc. Toscana di Sc. Natur. in Pisa*, vol. **17**, pp. 4–8, 1907.

[13] Rosický, V., *Bull. international de l'Academie des Sciences de Bohême*, vol. **13**, 1908.

[14] Ungemach, H., *Bull. Soc. Fran. Mineral.*, tome **44**, p. 123, 1921.

References 12 and 13 not available to the writer.

SUMMARY

The adamite from Gold Hill, Utah, occurs as individual crystals of a pale honey yellow color and as colorless rosettes. The indices of refraction are: $n_\alpha = 1.711 \pm 0.003$, $n_\beta = 1.732 \pm 0.003$, $n_\gamma = 1.756 \pm 0.003$, and the mineral is optically positive. The forms present are: $d\{101\}$, $m\{110\}$, $b\{010\}$, $l\{210\}$, $n\{120\}$. The axial ratio is, $a:b:c = 0.9742:1:0.7095$.

THE MINERALS OF THE WHITE RAVEN MINE, WARD, COLORADO

ERNEST E. WAHLSTROM, *University of Colorado, Boulder, Colorado*

The White Raven Mine is located in California Gulch, which is about a mile south of the old mining town of Ward, Boulder County, Colorado. The White Raven Mine has been a heavy producer of silver in past years, especially in 1913 and the immediately following years. It is estimated that $800,000 in lead and silver have been produced since 1913.

The ore bodies of this mine are especially interesting because they are of an unusual type in the Ward District, which was known in the early days for its gold production. This paper contains a study of the individual minerals, their occurrence, and origin.

A brief summary of the geology of the White Raven Mine and the surrounding area follows.[1] The country rocks of the area are igneous and metamorphic. The nearest unmetamorphosed sediments lie along the east flank of the Front Range of the Colorado Rockies, and are about ten miles to the east of the area under discussion. Pre-Cambrian schists, gneisses, granites, and quartz diorites constitute about two thirds of the exposed rocks. Tertiary (?) rocks, including small batholiths, stocks, and dikes of acid to intermediate intrusives occupy most of the rest of the area. There are a few small basic intrusions.

The White Raven Mine is located on a fissure vein in massive gray pre-Cambrian granite, which contains a few inclusions of schist. Intruded into the granite, roughly parallel to, and in places cut by the vein, is a dike of monzonite porphyry which is probably genetically related to the vein. The White Raven vein strikes approximately west and dips steeply to the north.

An investigation of the vein and its minerals by the present writer has resulted in the observations and conclusions described in the following parts of this paper.

The lead-silver ore was formed in a fissure which resulted from the reopening and brecciation of an older vein of gold-bearing quartz-pyrite-chalcopyrite ore. Brecciated fragments of this ore are found in many places in the vein and are covered in most cases by a coating of galena and siderite. These relations prove that the lead-silver vein is of a later date than the quartz-pyrite-chalcopyrite mineralization.

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[1] Adapted from a summary by P. G. Worcester, The Geology of the Ward Region, Boulder County, Colorado: Bull. **21,** *Colo. Geol. Survey,* 1920.

The following minerals have been found in important amounts in the ore shoots of the lead-silver vein: horn quartz, manganiferous siderite, barite, galena, and native silver. Other minerals occurring in minor amounts are pyrite, sphalerite, and calcite. The lower levels of the mine, at present inaccessible, have been reported to contain tennantite in addition to the minerals mentioned. In many places in the mine the minerals occur as layered coatings in openings or "vugs," many of which are a foot or more across. These openings have permitted the free growth of crystals of siderite, galena, and barite.

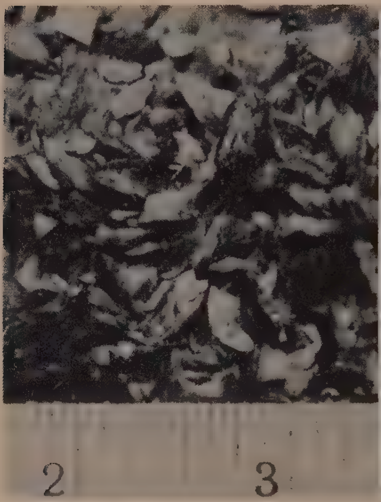


Fig. 1. Manganiferous siderite, White Raven Mine, Ward, Colo. The small white crystals are barite.

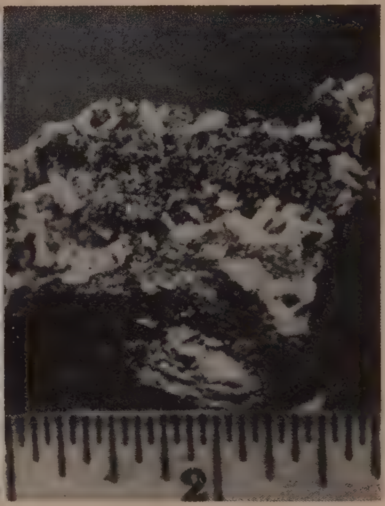


Fig. 2. Mat of wire silver on barite crystals, White Raven Mine, Ward, Colo.

The minerals appear to have formed in the following order: horn quartz, massive galena with small amounts of pyrite and sphalerite, manganiferous siderite, crystallized galena, manganiferous siderite, and finally, native wire silver. It is seen that the solutions from which the minerals were deposited varied and that the galena and siderite were deposited at two distinctly different periods. Further evidence pointing toward a variation in the chemical character of the solutions is the fact that some specimens from the vein show casts of barite. It appears that the barite was dissolved because of a change in composition of the solutions. In addition, some of the galena crystals show distinct etch patterns.

The most conspicuous vein mineral is the manganiferous siderite. Because it varies somewhat in general appearance from place to place within the vein, the writer made chemical analyses of three different specimens, and crystallographic measurements on two of the three analyzed specimens in an effort better to understand the variations. The analyses follow:

	No. 1	No. 2	No. 3
FeO	40.37%	38.11%	42.69%
MnO	18.62	22.85	16.95
CaO	1.17	0.55	0.05
MgO	1.26	0.02	0.10
ZnO	0.42	0.80	0.50
CO_2	38.95	38.40	37.63
Insol.	—	—	2.94
	100.79%	100.73%	100.86%

No. 1. East drift, main level, White Raven Mine, Ward, Colo.

No. 2. Stope, intersection of crosscut and drift, main level, White Raven Mine, Ward, Colo.

No. 3. Black Jack Tunnel, drift on White Raven vein, Ward, Colo.

Using the above analyses, and correcting for the insoluble residue in No. 3, the carbonates are found to have the following molecular percentages:

	No. 1	No. 2.	No. 3
$FeCO_3$	65.10%	61.45%	70.92%
$MnCO_3$	30.17	37.02	28.29
$CaCO_3$	2.08	0.98	0.09
$MgCO_3$	2.63	0.04	0.21
$ZnCO_3$	0.64	1.23	0.79

An inspection of the above analyses shows that there is considerable variation in the composition of the carbonates from place to place within the vein. The high percentage of manganese carbonate is noteworthy. All three of the samples analyzed approach manganosiderite in composition.

The color on the fresh surface of the siderite is a light grayish-brown. This color varies from slightly lighter to slightly darker shades from place to place within the vein. The siderite is in many cases coated with a film of dark manganese and iron oxides, formed by the oxidation of the manganese and iron in the carbonates.

Measurements of the acute angle between the rhombohedral cleavage faces, using a Fuess reflecting goniometer, gave the following results: carbonate No. 1, 73.1 degrees, average of 12 readings; carbonate No. 2, 73.0 degrees, average of 12 readings. Because of the fact that the surfaces of the siderite crystals are curved, it was found necessary to use very small cleavage pieces for the measurements, and as a result, the individual readings varied somewhat. Carbonate No. 3 was too dull and earthy to measure.

The characteristic occurrence of the manganiferous siderite is as a lining in "vugs," where it forms well developed crystals with the other vein minerals. The crystals vary considerably in size. The smallest crystals are microscopic, and the largest crystals are as much as three quarters of an inch wide. The crystals appear as flat rhombohedrons, and upon close inspection are seen to have curved surfaces similar to those frequently found on dolomite crystals.

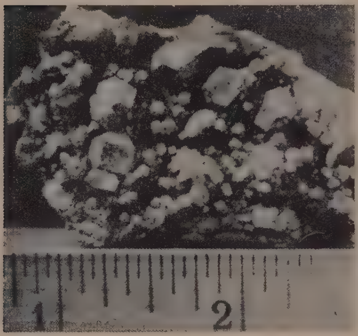


FIG. 3. Galena crystals from the White Raven Mine, Ward, Colo. The crystals show a combination of a cube and an octahedron.

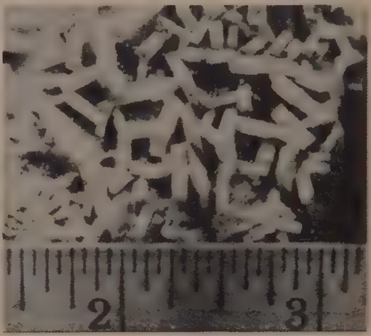
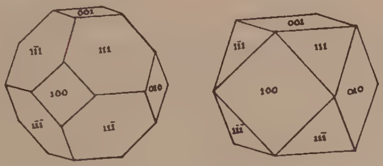


FIG. 4. Barite crystals from White Raven Mine. The coating seen on some of the crystals is siderite.

The barite occurs as simple, tabular crystals partly or completely embedded in the siderite, indicating that it started to form in the veins before the precipitation of the first generation of siderite was complete. However, in many specimens that were examined, the second generation of siderite has completely covered the barite, so that its presence may be observed only by examining a cross-section of the vein. The largest crystals of barite are about three quarters of an inch long and half an inch wide. The crystals are zoned and have a transparent core surrounded by a thin layer of white barite. Many of the barite crystals are encrusted with small crystals of galena and siderite.

The galena is found in crystals showing a combination of cube (100) and octahedron (111). Many of the galena crystals are distorted and have tabular or elongated shapes because of rapid growth in a direction parallel to an octahedron face. This type of crystal is shown in figure 7. The surfaces of the galena crystals have a dull appearance, and a few crystals show well developed etch patterns formed, possibly, by the action of solutions of the same origin as those from which the galena and other vein minerals were deposited. The largest galena crystals are about three quarters of an inch in diameter.



Figs. 5 and 6. Drawings of galena crystals showing combination of cube (100) and octahedron (111), White Raven Mine, Ward, Colo.

The last primary mineral to be formed in the vein was native wire silver. It is present only in certain restricted zones within the mine, and is usually found as a coating on the other vein minerals in "pipes," which are subcircular enlargements in the vein extending down the dip. Several samples taken from the mine show a heavy mat-like covering of fine, interlacing wires of silver. The individual wires are about as thick as a hair and have a maximum length of half an inch.

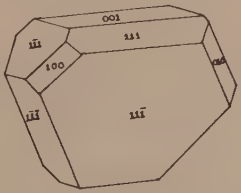


Fig. 7. Drawing of distorted crystal of galena, White Raven Mine, Ward, Colo.

Secondary minerals formed by the action of downward moving surface waters are calcite, which occurs in small, colorless crystals and in granular masses, and hydrous iron and manganese oxides.

The solutions from which the minerals were precipitated probably were intimately associated with the intrusion of the dike rocks in the Ward Region. Because the minerals occur in many cases as linings in large "vugs," it is believed that conditions of medium to low pressure prevailed during the precipitation. It is difficult to imagine the existence of the "vugs" under a high pressure, particularly when it is considered that the material in which the "vugs" exist is a loosely consolidated breccia, which in many places is cemented only by the manganiferous siderite. The fact that certain portions of the vein are hundreds of feet away from the nearest late igneous intrusion and the fact that the wall rocks of the vein are in many places fresh indicate that the temperature of the mineral bearing solutions was probably medium to low.

The changes in the solutions so as to cause precipitation of the minerals were probably complex. It seems reasonable to think that slowly cooling, ascending magmatic waters percolated through a brecciated zone in the granite and first deposited a layer of colloidal quartz which solidified to form the horn quartz. This layer of quartz was fractured by movement along the fissure. The cooling solution then became saturated with metallic sulphides, and galena, pyrite, and sphalerite were precipitated. Further cooling resulted in the formation of the manganiferous siderite and barite. After the deposition of the barite the solutions changed, possibly due to the renewal of igneous activity near the source of the solutions, and the solutions became saturated with sulphides and carbonate for the second time.

As the solutions continued to percolate through the fissure, they began to etch and corrode the previously precipitated minerals. Some of the barite crystals were dissolved completely, leaving casts; and some of the galena crystals were etched, producing dendritic patterns.

The origin of wire silver is more hypothetical. It seems that the research of Kohlschutter and Eydmann[2] has resulted in a satisfactory explanation of the formation of wire silver. They have proved experimentally that wire silver may be formed by either the oxidation or reduction of argentite under conditions of moderate temperature, and they believe that the wire silver of Freiberg and other European localities was formed in this way. It seems probable that the wire silver of the White Raven Mine was also formed in like manner. Argentite might be expected to be a logical accompaniment of the other sulphides found in the vein; hence, although argentite was not found by the writer, it may be present as minute disseminations in the argentiferous galena.

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[2] V. Kohlschutter and E. Eydmann, *Liebig's Annalen der Chemie*, vol. **390**, pp. 340–364, 1912.

In conclusion, the writer wishes to express his appreciation to Dr. R. D. Crawford of the University of Colorado for his friendly advice in matters pertaining to the above work, and for his critical reading of the manuscript.

NOTES AND NEWS

A SERICITE OF UNUSUAL COMPOSITION

Dorothy Babcock Meyer, *St. Louis, Missouri.*

Introduction

Pilot Knob is a conically shaped mountain located one mile northeast of Ironton, Missouri, and is similar to others that characterize that part of Missouri. The lower part of the mountain is the typical rhyolite porphyry of the area. Beds of specular iron ore rest on the porphyry and above the iron ore is one hundred or more feet of a ferruginous conglomerate that forms the top of the mountain.

A dominantly greenish but also gray or tan colored mineral is found in this conglomerate. The mineral occurs in variously sized masses, some nearly as large as a football, but the majority only two or three inches across. They are very irregularly shaped and appear to be either altered pebbles that compose the conglomerate, or streaks of material between the pebbles. They occur throughout the conglomerate.

The mineral ranges in hardness from 1 to 4. Usually the fresh material is soft, but after exposure it becomes harder. Because of its soft greasy feel it has often been called steatite. Some specimens show a lustrous surface indicating the micaceous character of the mineral, other specimens are dull. As noted above, it is dominantly green, but gray, tan, yellow, red, and even purple colored varieties have been noted.

This mineral has been given various names, most often steatite, by those who have studied the Pilot Knob iron ores. The mineral was called steatite or clay by Raphael Pumpelly;[1] serpentine by Adolf Schmidt;[2] steatite by J. R. Gage;[3] sericite by Frank Nason;[4] and talcose clay by G. W. Crane.[5] In view of this disagreement as to its character and the incomplete data relative to its composition, it was decided to investigate the material and to determine, if possible, the composition and the correct mineralogical name. The mineral analyzed was collected by Professor W. A. Tarr.

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[1] *Report of the Geol. Sur. of Missouri*, Part **1**, pp. 4, 15–16, 1872.

[2] *Ibid.*, p. 113.

[3] *Trans. Acad. Sci., St. Louis*, vol. **III**, p. 189, 1873.

[4] *Missouri Geol. Survey*, vol. **II**, *Report on the Iron Ores*, pp. 38–39, 1892.

[5] *Missouri Bur. Geology and Mines*, vol. **X**, 2nd series, p. 128, 1912.

COMPOSITION

The mineral was examined qualitatively by chemical, mineralogical, and optical tests. Iron, aluminum, potassium, sodium, silicon, and water were found to be present. The quantitative determinations gave the following results:

	1.	2.	Average
SiO_2	47.30	47.30	47.30
Al_2O_3	36.38	36.24	36.31
Fe_2O_3	2.17	2.17	2.17
Na_2O	5.26	5.28	5.27
K_2O	2.63	2.78	2.70
H_2O	5.75	5.86	5.80
	99.49	99.63	99.55

Although the physical characters suggested sericite, the above analysis showed the sodium to be present in larger amounts than potassium. This composition lead to a study of the available analyses of sericite and related minerals in order to determine its true chemical relationship. It was found that very few chemical analyses of sericite are available. The available analyses of sericite show the alkali content varying from almost 12% K_2O and no Na_2O to almost equal amounts of the two alkalies. Dana shows in the following analysis almost equivalent quantities of the two alkalies.

	Sericite[6]
SiO_2	54.00
Al_2O_3	26.23
Fe_2O_3	3.81
MgO	0.83
CaO	0.52
K_2O	4.41
Na_2O	4.00
TiO_2	1.51
H_2O	4.31
	99.62

The silica and total alkali content of the Pilot Knob mineral is quite similar to paragonite, but the alumina content, as well as other properties, indicate that it is not paragonite.

[6] Dana, *A System of Mineralogy*, **1895**, p. 618, No. 40.

Winchell[7] makes the statement that: "Recent data (Shannon[8]) suggest that sericite contains less potash and more water***** than ordinary muscovite." This is true of the mineral under discussion. In common muscovite the ratio between water and the alkalies is 2 to 1. In the Pilot Knob mineral the ratio is nearly 3 to 1. Dana[9] states that: "Mica at times becomes hydrated, losing its elasticity and transparency, and often some portion of the potash; and at the same time it may take up magnesia, lime, or soda. These changes may be promoted by waters containing carbonates of these bases."

Although the molecular formula $3\ (H,K,Na)_2O.3(Al,Fe)_2O_3.6\ SiO_2$ or $(H,K,Na)_3(Al,Fe)_3(SiO_4)_3$, derived from the chemical analysis of the mineral studied, approaches the formula for sericite as closely as most of the analyses, the higher water content and lower percentages of the alkalies yield ratios of nearly 3 to 1 instead of 2 to 1. The slightly higher percentage of silica as well as the ferric oxide are probably due to impurities. A few flakes of specularite (Fe_2O_3) could be seen in the mineral with a binocular microscope. Its presence is to be expected because the material was derived from a conglomerate associated with a specularite deposit.

OTHER PHYSICAL PROPERTIES

The specific gravity of the mineral used in this study was determined to be 2.69, while the specific gravity of sericite is generally given as $2.67-2.83$.[10] This wide range doubtless is due to the variable chemical composition of sericite. The presence of a larger amount of soda than of potash in the Pilot Knob mineral would tend to decrease its specfic gravity as compared with normal sericite. Sericite, as well as the mineral studied, when heated before the blowpipe fuses to a white-gray enamel. This aids in distinguishing the mineral from kaolinite and muscovite.[11]

Apparently no work on the dehydration of sericite has been done. The dehydration curve of the material studied (see Fig. 1.) shows a very slight loss of water between the temperatures of 85°–450° and from 600°–1080°C. Between 450°–600° a rapid loss of water was noted. This gives a very distinct curve that is somewhat similar to the dehydration curves of many clay minerals as plotted by Ross and Kerr.[12] The curve for sericite is so distinctive that it should be useful in future determinations of the mineral. The water content for sericite is consistently given between 4.5 and 6 per cent. The mineral studied has 5.80 per cent of water.

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[7] Winchell, N. H., and Winchell, A. N., *Elements of Optical Mineralogy*, p. 363, 1927.

[8] *Proc. U. S. Nat. Mus.*, vol. **62**, Art. 15, p. 10, 1923.

[9] Dana, *Loc. cit.*, p. 620.

[10] Dana, *Loc. cit.*, p. 620.

[11] Shannon E. V., *Ibid.*, pp. 6–11.

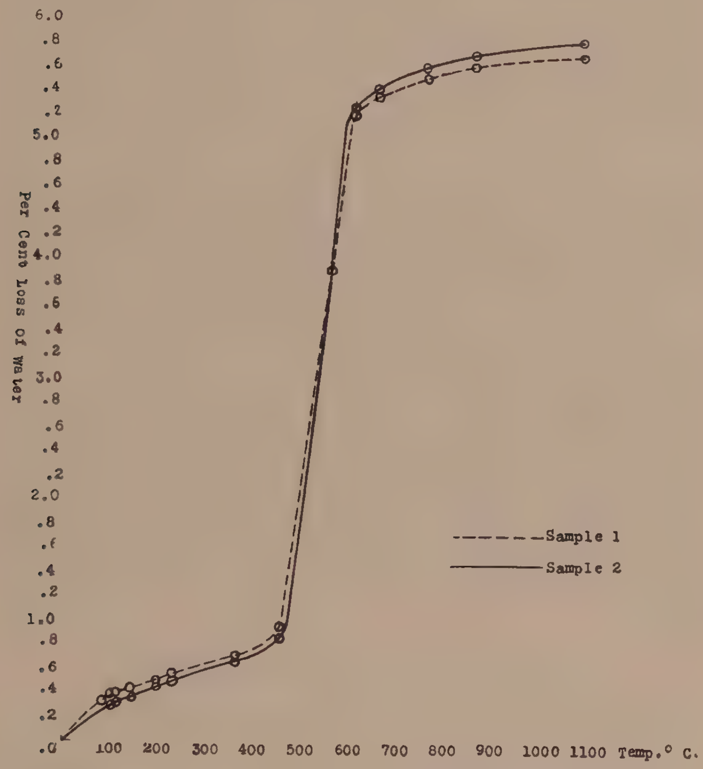

FIG. 1. Dehydration curve of sericite from Pilot Knob.

The crystals of the investigated material were too small to obtain any optical data other than a mean index of refraction. This value was determined as 1.580 ± .003. Ross[13] gives the indices of refraction of sericite from the Carroll-Driscoll Mine in Boise County, Idaho, as 1.585± .003 for beta and 1.587± .003 for gamma. Both of these indices are close to the single mean index 1.580 found for the material analyzed. The indices for sericite and muscovite are similar, but paragonite has indices somewhat higher, 1.60.[14] Because of its high soda content a further check upon its identification seemed desirable, hence, a sample was sent to Dr. Paul F. Kerr of Columbia University, for x-ray analysis. He reported that the x-ray pattern was that of the mineral sericite, thus furnishing conclusive proof as to the identification of the mineral.

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[12] Ross, C. S., and Kerr, P. F., The Kaolin Minerals: pp. 166–167. *U. S. Geol. Survey, Prof. Paper* **165E,** 1931.

[13] Shannon, E. V., Notes on the Mineralogy of Three Gouge Clays from Precious Metals Veins: *Proc. U. S. Nat. Mus.*, vol. **62,** Art. 15, 1923. Optical work done by C. S. Ross.

Origin

As noted above the sericite occurs scattered irregularly through the conglomerate at the top of Pilot Knob. This conglomerate contains many varieties of rocks but certain ones have evidently been more susceptible to the type of alteration that produced the sericite. Although commonly derived from orthoclase or microcline, sericite may also be derived from plagioclase feldspars. The composition of the sericite from Pilot Knob suggests that it was derived from plagioclase or that the potash had been replaced by sodium. A mixture of albite and orthoclase might well have been the original source material thus furnishing both the alkalies.

From the above data on its physical, chemical, the optical properties that could be determined, and the x-ray pattern, the mineral undoubtedly belongs to the muscovite mica group of minerals and is sericite.

LINEAR MINERALOGICAL ARITHMETIC

A. L. Parsons, *University of Toronto, Toronto, Canada.*

In calculating the norm of a rock from a chemical analysis it is customary to divide the percentages of the oxides by the molecular weights to obtain the molecular proportions, or to consult tables of molecular proportions. From these proportions the minerals are calculated by multiplying certain molecular proportions by the molecular weight of the mineral concerned. With tables giving the molecular proportions to three decimal places the total mineral percentage seldom agrees with the total for the analysis.

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[14] Larsen, Esper S., The Microscopic Determination of Nonopaque Minerals, *U. S. Geol. Survey*, Bull. **679**, p. 254.

In the present paper a graphic method of determining molecular proportions with a high degree of accuracy and the calculation of the mineral percentages is shown. In figure 1 the vertical co-ordinates give percentages and the horizontal ones from the right give molecular proportions or the percentage of the compound concerned divided by its molecular weight.

For demonstration a theoretical analysis obtained by adding the percentages of the oxides in calcite, magnetite, andradite, anorthite and grossularite and dividing by five was taken. For comparison the molecular parts tabulated in Kemp's *Handbook of Rocks* were used for arithmetical calculation along with a direct calculation by the writer. The molecular parts to be taken directly or deduced from the tables of Holmes and Von Eckerman are also added but not used for calculation. (Table I.)

TABLE I

THEORETICAL ANALYSIS

	Per cent	Molecular Parts				
		Kemp	Holmes	Parsons	Parsons Graphic	Von Eck.
SiO_2	23.74	.396	.396	.3957	.3960	.3937
Al_2O_3	11.88	.116	.117	.1165	.1162	.1162
Fe_2O_3	20.10	.125	.126±	.1256	.1258	.1259
FeO	6.2	.086	.086	.0861	.0866	.0863
CaO	29.28	.523	.524	.5229	.5231	.5220
CO_2	8.8	.200	.200	.2000	.2000	.2000

The percentages found using Kemp, Parsons and Parsons Graphic are as follows:

TABLE II

	Kemp	Parsons	Parsons Graphic
Calcite	20.000	20.0000	19.99
Magnetite	19.952	19.9752	20.00
Andradite	19.812	20.0666	19.99
Grossularite	20.250	19.7775	20.00
Anorthite	19.738	20.1689	19.99
Quartz	0.012	0.0150	—
	99.764	100.0032	99.97

In proceeding by the graphical method the original chart was made one metre square and on the left hand the molecular weights were laid off as vertical co-ordinates. These points were connected with the origin at the lower right hand corner. Figure 1 is a portion of the original chart. Points were then determined indicating the percentages of the different constituents shown in the analysis and automatically the molecular proportions were marked off. Calcite was first determined by drawing a vertical line from the CO_2 point to the $CaCO_3$. In similar manner magnetite was determined from the FeO, leaving an excess of Fe_2O_3 which was transferred to the origin thus marking off the point for drawing the line for andradite.

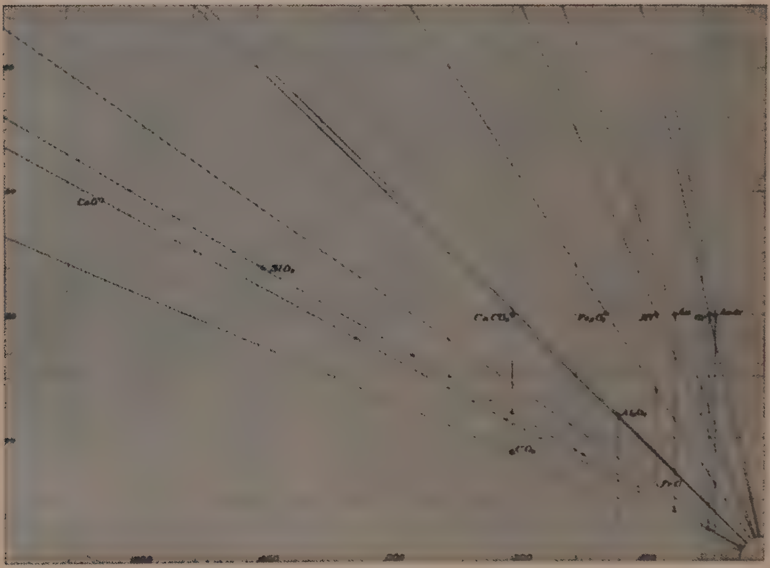

Fig. 1

The residue was now lime, alumina and silica. The quantity of lime that was used up in calcite and andradite was now subtracted from the total lime and a vertical line drawn from the point representing the Al_2O_3. Molecularly the lime was in excess of the alumina. This excess was divided by two and subtracted from the alumina value, thus locating the point through which the vertical line should be drawn for the anorthite. This same value was measured from the origin to indicate the point through which the vertical line should be drawn for the grossularite. When this was done the quantities of silica used for grossularite and andradite were subtracted from the total by means of dividers and the residue was so nearly bisected by the vertical line for anorthite that it involved an error of less than one-fifth of a millimeter.

This graphic method provides a means of preparing tables of molecular proportions with a great degree of accuracy. It also provides for a similar accuracy in calculating the norm of a rock.

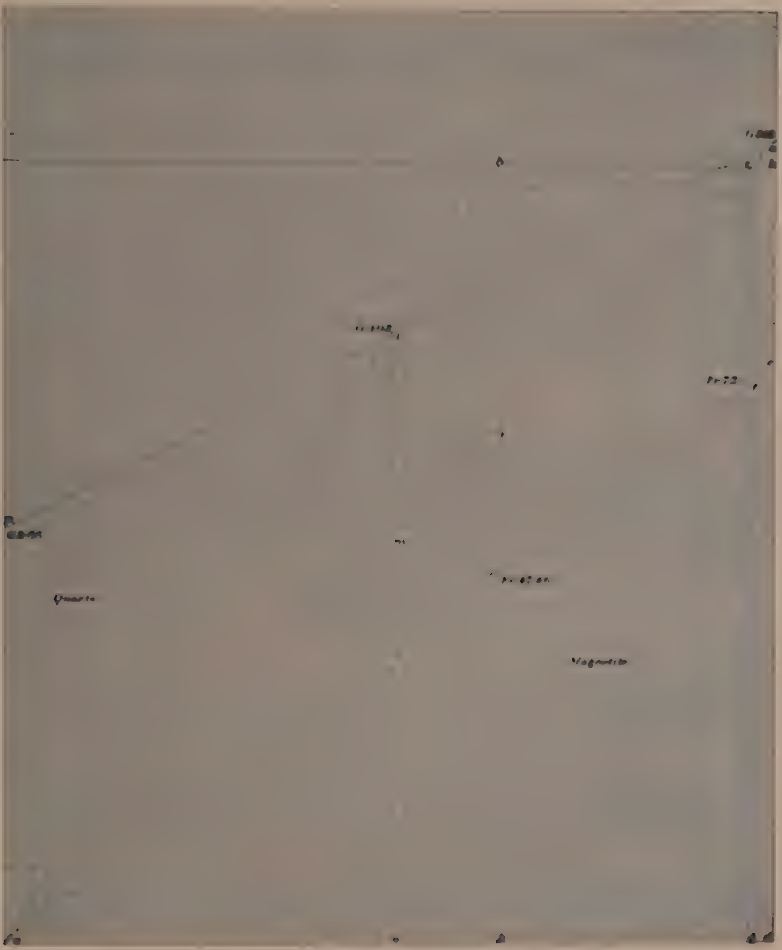

FIG. 2

Another problem which frequently comes up in a practical way is the determination of the percentage of some element in a two component mixture. Possibly more has been written concerning this in connection with the determination of the percentage of iron in an ore when the specific gravity is known.

In general determinations of percentages of any element from the specific gravity can probably not claim a greater accuracy than ±1 per cent, but the difference between the arithmetical method and the graphic method will not be greater than 0.2 per cent. The method of determining the percentage of iron in a two component system consisting of quartz and magnetite is shown in figure 2.

In figure 2 the specific gravity of quartz is laid off as a vertical co-ordinate on the left and the specific gravity of magnetite on the right. The line *ap* gives the specific gravity of any and every mixture of these two by bulk. The line *aq* is the dividing line between quartz and magnetite. The line *bh* is the 100% line. Magnetite contains 72+per cent of iron.

$$\frac{cd}{ac}=\frac{fg}{eg}=\frac{72}{100}$$

Now for any mixture of quartz and magnetite (in the figure equal parts are taken) join the origin *q* with the point marked by the specific gravity *l* and produce to the 100 per cent line at *h*. Draw the line *hk*. Then

$$\frac{no}{lo}=\frac{jk}{hk}=47.46\%$$

Arithmetical calculation gave 47.57%.

This graphic method provides an easy check on concentration and may be modified so as to introduce the average specific gravity of a rock instead of using that of quartz. In general it will not be applicable to mixtures of liquids for usually a change in volume is involved.

SPECTROGRAPHIC EXAMINATION OF SMOKY AND ORDINARY QUARTZ FROM RINCON, CALIF.

T. G. KENNARD*

Inasmuch as the color of smoky quartz is attributed by many investigators[1,2,3,6] to the presence of finely divided particles of silicon, rather than to the presence of some other coloring substance, spectrographic analyses were made on samples of very pale and very dark smoky quartz obtained from different parts of the same crystal or specimen, in order to ascertain whether or not any variation in composition might be thus found.

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* Research Fellow in Chemistry, Claremont Colleges, Claremont, Calif.

[1] Holden, *Am. Mineral.*, vol. **10**, pp. 203–52, 1925.

Klemm and Wild,[4,5] on comparing the spark spectra of samples of clear (rock crystal) and smoky quartz which were fused in lithium carbonate, found that all the spectra showed the same lines. Excitation by means of a carbon arc revealed the presence of lithium and sodium in all the varieties of quartz examined. In a later paper Klemm[6] stated that smoky quartz always showed only the spectrum of silicon. By means of spectroscopic tests Holden[1] found traces of lithium and sodium, a trace? of potassium, but no strontium or barium, in a sample of smoky quartz. Unweighable amounts of sodium and lithium were detected spectroscopically in quartz by Königsberger.[7]

Preparation of Samples

Samples of various color types of ordinary and smoky quartz were selected from the following specimens, all of which had been collected personally at the Clark mine,[8] near Rincon, California. While transparent crystals were found which were water-white at one end, and slightly smoky at the other, the writer was unable to obtain crystals suitable for examination which showed a similar variation in color from water-white to very dark. Consequently, material was used in which the color varied in the same specimen from a very pale smoky tint to a very dark, smoky brown color.

Specimen no. 1. This was a singly terminated, transparent quartz crystal approximately 8 mm. in diameter and 3 cm. long, which showed well-developed prismatic and rhombohedral faces. The color varied fairly uniformly from very dark,

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[2] A bibliography of important papers on smoky quartz and amethyst is given by Holden, *loc. cit.*, pp. 250–52.

[3] Hoffman, *Zeit. anorg. allgem. Chem.*, vol. **196**, pp. 225–46, 1931.

[4] Klemm and Wild, *Centr. Mineral., Geol.*, **1925A**, pp. 270–3.

[5] Wild, *Centr. Mineral., Geol.*, **1930A**, pp. 428–31.

[6] Klemm, *Zeit. angew. Chem.*, vol. **40**, pp. 221–4, 1927.

[7] Königsberger, *Tsch. min. Mit.*, vol. **19**, p. 149, 1900. Doelter, *Handb. d. Mineralchemie*, II, **1**, p. 120.

[8] This mine is located in the W. ½ of Sec. 36, T. 10 S., R. 1 W., S. B. B. & M., Ramona quad., and is north of the San Luis Rey River, on the southeasterly slope of the main ridge.

smoky brown at the terminated end to nearly colorless, but perceptibly smoky gray, at the other end. Sample no. 1-*a*, which was taken from the nearly colorless end, was apparently water-white when a thickness of 2 mm. was examined, but showed a very pale smoky color, somewhat lighter than 17''''*f*,[9] perhaps that of 17''''g, when 8 mm. thick. Sample no. 1-*b*, taken from near the dark end, was apparently opaque in the 8 mm. thickness when placed on a piece of white filter paper, and examined by reflected light, but was found transparent by strong transmitted light. The color, by reflected light, for a fragment 2 mm. thick, was similar to that of sample no. 4, but was slightly lighter.

Specimen no. 2 was an irregular-shaped mass of quartz approximately 7×5×4.5 cm. in size. One side of the specimen showed a very dark, smoky brown color; the other was very pale smoky gray. The color transition from light to dark was very abrupt, forming a well-defined plane of demarcation running lengthwise thru the specimen. By careful splitting and trimming, first with a steel hammer, and then with a lump of quartz, a piece of quartz approximately 11×10×7 mm. in size was obtained from the interior portion of the specimen. From this piece, half of which was dark, and the other half light, the final samples were obtained. No particular tendency was observed on crushing for this piece to split along the color plane, since a number of tiny fragments one to two mm. across were found to contain both the light and the dark material. Sample no. 2-*a*, from the light portion, appeared water-white in a thickness of 2 mm., but showed a very pale smoky color, somewhat lighter than 21''''f, perhaps that of 21''''*g*, when 8 mm. thick. This material was. slightly less transparent than sample no. 1-*a*, which was very clear. Sample no. 2-*b*, from the dark portion, was similar in color to sample no. 4, but was slightly lighter.

Specimen no. 3 was a large, massive piece of very transparent quartz, approximately 11×7×3 cm. in size. This material was water-white in a thickness of 11 cm.

Specimen no. 4 was a massive piece 7×3.5×2.5 cm. The color was very dark smoky brown, or bister. Sample no. 4, which was taken from this fragment, showed a color approximating 15''*m*.

Altho specimens nos. 3 and 4 were not originally parts of a larger, single piece of quartz, as far as known, they were selected as types of the clearest colorless quartz and the darkest smoky quartz, collected by the writer at this locality. Thus samples nos. 3 and 4 came from separate pieces of quartz obtained from the same locality, whereas samples nos. 1-*a* and 1-*b* came from parts of the same crystal not over 25 mm. distant from each other, and samples nos. 2-*a* and 2-*b* came from places not over 11 mm. apart in a massive piece of quartz. All of the material used was transparent in a 2 mm. thickness.

In preparing the samples, the large specimens of quartz were cracked by means of a steel hammer. Further trimming and crushing was done between large, nearly flat-surfaced, freshly split pieces of quartz from the same locality, using clear quartz to crush the small, selected portions of the clear quartz, and smoky quartz for the smoky material. Before crushing, the small, selected pieces were wrapped in ashless filter paper (Whatman No. 40), partly to prevent fragments of the crushing stones from being included in the sample, and partly to avoid scattering of the crushed material. The pieces selected for the final crushing were taken from interior portions of the specimen (for specimens Nos. 2, 3 and 4), thus avoiding metallic contamination from the steel hammer, and other surface contamination. Likewise, the crushing surfaces had been freshly exposed by splitting larger pieces.

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[9] The color designations are those given in Ridgway, *Color Standards and Color Nomenclature*, Washington, **1912**.

After crushing, suitable fragments of quartz, the average weight of which was about 30 mg., were selected, washed twice in benzene to remove dust and tiny adhering particles, and examined microscopically. Only those fragments were retained which showed freshly broken surfaces and which were visibly free from large inclusions and surface contamination. Strips of filter paper (Whatman No. 2) were used in this handling, and the washed and selected material was kept on other pieces of paper until used.

All of the quartz examined showed the presence of a very few minute specks or inclusions, the nature of which was not determined, and which showed little characteristic shape under a magnification of 385×. The maximum diameter observed on any of the particles was 0.002 mm. Assuming the particles to be spherical, an estimation of the average number observed per fragment of quartz indicated that the volume percentage of the inclusions in the quartz was less than 0.000,04%. The various samples of clear and smoky quartz all showed approximately the same relative amounts of inclusions.

SPECTROGRAPHIC PROCEDURE

The spectra were excited by means of a vertical, 100 volt D.C. arc operated on a current of 10–12 amperes, and were photographed by means of a large Gaertner quartz spectrograph, using Eastman D.C. plates in the ultra-violet, and W. & W. Panchromatic plates in the visible portion of the spectrum. A slit width of 0.035 mm. was used. The arc was placed 38 cm. from the slit, and aligned vertically in such a manner that the light which entered the collimating system of the spectrograph came principally from the lower 3/5 of the arc. This arrangement had previously been found to result in increased sensitivity for many of the metallic elements. In order to maintain the desired arc alignment, an auxiliary convex glass lens of approximately 21 cm. focal length was used to project an enlarged image of the arc upon a screen fastened on the wall on the opposite side of the room. Thus a shift in the position of the arc could be readily observed by watching the position of the projected image on the screen.

Acheson regraphitized graphite electrodes 9.5 mm. (3/8 inch) in diameter were used. These electrodes customarily show lines of various metallic impurities, and the intensity of these impurity lines varies with different pairs of electrodes, indicating non-uniformity of composition. Inasmuch as it was particularly desired to compare pairs of samples (smoky and light colored), this non-uniformity was compensated by the following method of selection of electrodes.

The graphite rods, which had been purchased in 30.5 cm. (12 inch) lengths, were broken into six pieces of roughly equal lengths. The two end pieces were rejected, to be used in other work. The remaining four electrodes were used in pairs so that the arcs were struck between the ends *AD* and *BC* (Fig. 1), keeping either *A* and *B*, or else *C* and *D*, as the top of the lower electrode. Thus two matched pairs of electrodes were available for comparing two samples. This selection of matched pairs of electrodes was found to give far greater uniformity in the blanks, or spectra of the electrodes alone, than the use of electrodes selected at random. The upper end of the lower electrode was slightly hollowed, by means of a steel knife, so as to form a shallow cup. Tests showed that electrodes thus treated showed no more iron than those which had not been hollowed with the knife.

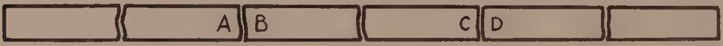

Fig. 1.

The procedure in all cases was as follows: After burning off each pair of electrodes for two minutes, the spectrum of the electrodes alone was photographed. The fragment of quartz was loaded by means of a strip of filter paper, and two or three successive exposures were made. The exposure time in photographing the spectrum was 30 seconds for the visible portion, and 40 seconds for the ultraviolet. The spectra of each pair of samples were placed on adjacent portions of the same photographic plate, thus insuring the same conditions of development. All samples were examined in duplicate.

In order to determine whether or not the benzene used in wash-ing the samples left a detectable residue, a sample of the benzene was allowed to evaporate slowly from the end of an electrode. Upon examination, no new impurity lines were noted, nor were those already present strengthened.

The plates were interpreted by comparison with standard plates showing the dilution spectra of the various elements, and the results are given in Table 1. While the spectrographic interpretation was largely qualitative rather than quantitative, it was possible, however, to compare relative amounts of a given element without evaluating in terms of percentage composition. Since the different fragments examined varied somewhat in weight, this range of variation was allowed for in interpreting the spectrograms.

Table 1

	Li	Al	V	Ti	Fe	Na	Ca	Mg	Si
Sample no. 1-*a* (light colored	tr	tr	trtr	tr	bl	bl	trtr	trtr	l
1-*a* " "	tr	tr	trtr	trtr	bl	bl	trtr	trtr	l
1-*b* (dark colored)	trtr	tr	trtr	tr	bl	bl	trtr	trtr	l
1-*b* " "	trtr	tr	trtr	tr	bl	bl	trtr	trtr	l
2-*a* (light colored)	tr	tr	tr	tr	bl	bl	trtr	trtr	l
2-*a* " "	tr	tr	trtr	tr	bl	bl	trtr	trtr	l
2-*b* (dark colored)	trtr	tr	trtr	tr	bl	bl	trtr	trtr	l
2-*b* " "	trtr	tr	trtr	tr	bl	bl	trtr	trtr	l
3 (light colored)	tr	tr	trtr	trtr	bl	bl	trtr	trtr	l
3 " "	tr	tr	trtr	trtr	bl	bl	trtr	trtr	l
4 (dark colored)	trtr	tr	trtr	trtr	bl	bl	trtr	trtr	l
4 " "	—	tr	trtr	tr	bl	bl	trtr	trtr	l

Key to symbols:

l = large amount.
tr = trace.
trtr = extremely minute trace.
bl = lines not stronger than those in the blank.

Results

The lines due to iron and sodium were not stronger in the spectra of the samples than in the spectra of the electrodes alone. Hence extremely minute traces of these elements may have escaped detection. All of the elements, except vanadium, which are listed in Table 1 have been previously reported in smoky quartz from Colorado by Holden.

For aluminum, calcium, magnesium, vanadium and titanium, no significant differences in content between the various samples were found. Lithium was much more pronounced in all of the samples of light colored quartz than in the darker, smoky material, and was largest in content, in fact, in the colorless and very clear sample no. 3. All the fragments of the dark, smoky quartz, however, except one, showed the presence of an extremely minute trace of lithium.

From the data obtained, it appears that with increasing lithium content a decreasing amount of smokiness is to be expected in the quartz from this locality. Whether this inverse relationship holds for colorless and smoky quartz from other localities is not known to the writer. It is likewise unknown whether a decrease in lithium content is directly responsible for an increase in smokiness, or whether the conditions which favor an increase in depth of smoky color, may, perhaps indirectly, tend to reduce the lithium content in the crystal, or in the solution and/or vapor from which it may be formed. It has been suggested that sodium and lithium, in the form of silicates, or otherwise, may play some role in the coloration of smoky quartz,[5,10] or may even be responsible directly for the coloration.[4,11,12] If smoky quartz is colored by finely divided particles of silicon, produced by radioactivity, perhaps the presence of lithium compounds in the crystal lattice tends to prevent the decomposition which results in the finely divided particles. This possibility could be tested by subjecting samples of clear, colorless quartz, which have been found to show a difference in lithium content, to suitable radiations, and observing whether or not there is a difference in the rate at which they darken or become smoky.

It is possible that the inclusions in the samples may be responsible, in part at least, for the elements other than silicon which were found present. These inclusions may possibly be responsible for the variation in lithium content. This latter possibility appears very unlikely, however, since the inclusions in the various samples appeared to be similar in nature and relative amount, and also since the estimated total amount of the inclusions is very small.

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[10] Doelter, *loc. cit.*, p. 144.

[11] Doelter, Das Radium and die Farben, pp. 124–125, Dresden. Die Farben der Mineralien, pp. 70–75, Braunschweig.

[12] Hoffmann, *Zeit. anorg. allgem. Chem.* vol. **219**, pp. 197–202, 1934.

SUMMARY

1. Colorless, very pale smoky, and dark smoky quartz specimens from Rincon, California, have been examined spectrographically.

2. The colorless, as well as the very pale smoky quartz samples were found to contain more lithium than the dark smoky quartz, regardless of whether or not the various colored types formed parts of the same crystal or crystalline mass.

3. No other significant difference in composition, as regards metallic constituents, was found. Aluminum, vanadium, titanium, calcium, magnesium, and, of course, silicon, were found to be present in all of the samples examined.

4. An improved spectrographic technique for examining minerals is described.

TETRADYMITE FROM INYO MOUNTAINS, CALIFORNIA

ROBERT W. WEBB, *University of California at Los Angeles.*

Samples of a brilliant, foliated metallic mineral collected in the Cerro Gordo district, Inyo mountains, Inyo County, California, proved upon examination to be tetradymite. The occurrence of this mineral has not been reported, as far as the writer is aware, in the suite of minerals of the Cerro Gordo district.[1]

In a hand specimen the tetradymite occurs as myriads of brilliant tabular crystals about 1/16 inch in diameter. It is imbedded in an earthy, powdery, apple to pale green mineral identified as bismutite. Other associated minerals are quartz, and a straw yellow powder that has not as yet been positively determined.

The physical properties of the tetradymite are: luster, metallic, brilliant; color, tin white to light silver gray; hardness 1.5–2; perfect basal cleavage. No specific gravity determinations were made.

Qualitative chemical analysis indicates (a) trace of sulphur upon roasting, (b) no selenium, (c) presence of tellurium upon solution with concentrated sulphuric acid, (d) presence of bismuth upon fusion with potassium iodide and sulphur.

A polished section of the ore, prepared and examined by Mr. V. C. Kelley, of the California Institute of Technology, showed the following minerals: (a) rutile, two or three grains; (b) quartz; (c) tetradymite; (d) chalcopyrite, one or two very small grains; (e) a black mineral occurring in minute specks in the tetradymite, not as yet positively identified, but may be tenorite; (f) bismutite. Paragenesis: rutile, quartz, tetradymite, chalcopyrite, tenorite (?), bismutite.

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[1] Knopf, A., A Geologic Reconnaissance of the Inyo Range, etc., *U. S. Geol. Surv.*, Prof. Paper **110**, pp. 108–16, 1918.

Eakle, A. S., Minerals of California, *Calif. State Min. Bur.*, Bull. **91**, 1923.

The specimens were found in a brecciated quartz vein about four inches wide, in an open cut prospect in the quartz monzonite of the Inyo Mountains.

Dana[2] mentions tetradymite from but six states, and none of these localities are in California. However, Eakle[3] lists two occurrences in California (reported by Hanks[4]), and one other unconfirmed occurrence.

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[2] *Textbook of Mineralogy*, 4th edition, p. 412, **1932.**

[3] *Op. cit.*, p. 64, 1923.

[4] *4th Ann. Rept. State Mineralogist*, **1884.**

ON THE APPLICATION OF DETERMINANTS TO CRYSTALLOGRAPHY

P. Aloisi, *Royal University of Florence, Italy.*

The American Mineralogist published in its issue of December 1934 (vol. **19**, no. 12) a very interesting study by J. D. H. Donnay on "The theory of determinants applied to crystallography." It does not appear from the article whether the author considers the application of determinants to crystallography as something new or not; in any case the author does not mention anything to that effect.

I wish therefore to make it clear that priority, in this field, belongs to the Italian mineralogist Quintino Sella, who in the Notes A and B to his paper "Sul boro adamantino,"[1] submitted to the Academy of Sciences of Turin on the 14th of June 1857, and printed in 1858, showed that "the principal formulas of crystallography can be symbolically presented by means of the notations introduced by modern analysts in the calculus of determinants in a manner which is both concise and elegant."

The first problem treated by Sella, with the use of determinants, is precisely the first of those mentioned also by Donnay, that is, the condition which relates the indices of three faces in a zone. Subsequent to Sella's application of determinants to crystallography, the same method has been followed in Italy to the present day, in nearly all university courses of mineralogy, and in some treatises on morphologic crystallography.[2]

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[1] *Mem. R. Acc. delle Scienze di Torino*, Ser. 2, tomo **XVII**, Torino, 1858. Reprinted in "Memorie di cristallografia di Quintino Sella," *Mem. R. Acc. Lincei, Cl. di Sc. fis; mat, e nat.*, vol. **II**, Roma, 1885.

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[2] For instance; R. Panebianco, *Trattato di cristallografia morfologica*, Padova, **1904.**

PROCEEDINGS OF SOCIETIES

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, February 7, 1935.

Dr. Gillson presided at a stated meeting, 51 members and 35 visitors being present. Dr. Gillson spoke on "Some Mining Operations in England, Spain, and Sierra Leone." The lecture was illustrated by means of lantern slides. During 1935 he spent ten days at Cornwall, a month at Cologne, Germany, a week in Spain, and six weeks in Sierra Leone. The history and development of the tin mines of Cornwall were described, also the geologic origin of the deposits, and the financial difficulties of the various companies operating the mines. He visited the mercury mine at Almaden, which has been in operation since 1499, and produces ore averaging 7% quicksilver. Spain is also an important potash producer, a typical salt dome being located near Barcelona and Cardona. Sylvite and carnallite occur on the flanks of the dome. Dr. Gillson went to Sierra Leone to examine ilmenite deposits. The deposits are not commercially important and Sierra Leone, thought to be insignificant mineralogically, has been brought to our attention by Pollet, who has found deposits of diamond, gold, chromite, and platinum. At Marampa, 45 miles from the coast, there is an iron ore deposit estimated to contain 100,000,000 tons.

W. H. Flack, *Secretary*

BOOK REVIEWS

EDELSTEINE UND SCHMUCKSTEINE. Dr. Alfred Eppler. Second edition, revised and enlarged by Dr. W. Fr. Eppler. 554 pages, 317 illustrations, and 4 colored plates. Wilhelm Diebener, Leipzig, Germany. **1934.**

This revision of the well-known Eppler text, first issued in 1912, is especially designed for gem dealers, jewelers, artists, collectors, and admirers of gem stones. Written in the environment of Idar, Germany, the historic center of the gem-cutting industry, the author has been able to draw upon the long experience and great wealth of material of the community. This edition is a very welcome, as well as an important contribution to the literature of gem stones.

The nine chapters of the book are devoted to the following topics: Historical Survey of the Use of Gems; Chemical and Physical Properties and the Usual Methods for the Recognition and Determination of Ornamental and Gem Stones; Imitation Stones; Descriptions of the Various Stones; Occurrences and Production; Traffic in Uncut Stones; Ornamental and Gem Stone Industry; Names; and Determinative Tables.

The various chapters are well written. Emphasis is placed upon practical and commercially important matters, while highly technical features are held in the background. The descriptions of the gems are adequate and discriminating. Twenty pages are devoted to the pearl, forty to the stones of the quartz group, twenty-five to natural and synthetic corundum gems, and forty-four to the diamond and carbonado. A striking feature of the descriptions of the various gem stones is the space given to their behavior toward *x*-rays and to the properties of fluorescence and phosphorescence, which are now attracting so much popular attention. The different phases of the Idar gem-cutting industry are discussed in a very interesting manner.

The book is well illustrated. Some crystallographic drawings (Nos. 8, 16, 150, 173, and 198) are, however, not properly oriented. The four colored plates are superb. The colors of the stones are most faithfully reproduced. These plates are very beautiful and, in fact, the best of the kind the reviewer has ever seen.

EDWARD H. KRAUS

DIE LAGERSTAETTEN DER EDELSTEINE UND SCHMUCKSTEINE. DR. O. STUTZER AND DR. W. FR. EPPLER. 567 pages, with 154 illustrations. Gebrueder Borntraeger, Berlin, 1935.

This volume, dealing with gem and ornamental stones, is the sixth in the series on the formation and occurrence of the non-metallic minerals that is being prepared under the editorial direction of Professor O. Stutzer, of the Saxon School of Mines at Freiberg.

The book is divided into two parts. The first portion contains 216 pages and is devoted to the most important gem, the diamond. It was written by Dr. Stutzer. The second portion discusses those minerals other than the diamond that are useful as gems and ornamental stones. This part was prepared by Dr. Eppler.

Throughout the text the formation and important occurrences of the various gem minerals are described in a comprehensive and authoritative manner. Their uses and reliable statistics of production are also given. Bibliographic references are numerous, and especially in the second part are they conveniently listed together for each mineral.

This book should prove most helpful to mineralogists, economic geologists, and others interested in the formation, occurrence, and uses of gem minerals.

EDWARD H. KRAUS

GEOLOGY OF THE WESTERN SAN GABRIEL MOUNTAINS OF CALIFORNIA. WILLIAM J. MILLER. Publications of the University of California at Los Angeles, Vol. 1, No. 1, pp. 1–114, 13 plates, 6 figures, 1 map. University of California Press, Berkeley, Calif.

The San Gabriel Mountains are located immediately north and northeast of Los Angeles. Geologically they are a great block 4,000 to 10,000 feet high of pre-Cretaceous metamorphic and igneous rocks, bordered on all sides by Tertiary and

Quaternary sediments. The block is clearly a horst broken internally by many minor faults. The San Andreas fault bounds it on the northeast. The mountains were lifted to their present height in Quaternary time.

The major part of the study is concerned with the petrology of the crystalline rocks of the area, but also contributes valuably to the Cenozoic history and geomorphology of the district. A semi-detailed geologic map in colors accompanies the report. It is well written and illustrated.

A. J. Eardley

NEW MINERAL NAMES

Manganilmenite

Edward S. Simpson, Contributions to the Mineralogy of Western Australia. *Jour. Roy. Soc. W. Australia*, vol. **15**, p. 103, 1929.

Chemical Properties: A manganese bearing ilmenite: Fe_2O_3 12.12, FeO 21.27, MnO 14.40, MgO tr., TiO_2 51.79, SiO_2 0.80. Total 100.38.

Physical Properties: Brownish black with light brown coating. Imperfect cleavage. G=4.63.

Occurrence: As pebbles up to several centimeters in diameter from granite terrain traversed by pegmatite veins, a few miles south-east of Cunmagnunna, Trig. (B4) on Woodstock Station (Lat. 21°48′S. Long. 115°55′E).

W. F. Foshag

Scawtite

Tilley, C. E., Scawtite, a new mineral from Scawt Hill, Co. Antrim. With chemical analysis by M. H. Hey. *Mineral. Mag.*, vol. **22**, No. 128, pp. 222–224, 1930.

Name: From the locality, Scawt Hill.

Chemical Properties: Calcium silicate-carbonate. $4CaO \cdot 3SiO_2 \cdot 2CO_2$. Analysis (on .0812 gms.) CaO 46.4, SiO_2 34.2, CO_2 18.0; total 98.6. Readily decomposed by weak hydrochloric acid with marked effervescence, leaving a gelatinous residue.

Crystallographic Properties: Probably monoclinic. Cleavage (001) perfect, (010) trace.

Physical and Optical Properties: Colorless, luster vitreous. Biaxial positive. $2V=74°$. $\alpha=1.597$, $\beta=1.606$, $\gamma=1.621$. $Y=b$. $Z{:}c=29°$.

Hd.$=4\frac{1}{2}$–5. G=2.77.

Occurrence: Found in vesicles in the melilite bearing types of hybrid rocks at Scawt Hill, Co. Antrim, associated with calcite, thomsonite and an unknown zeolitic mineral.

W. F. F.

Ginorite

D'Achiardi, Giovanni, Ginorite, nuovo borato di calcio di Sasso Pisano. *Periodico Min. Roma*, vol. **5**, pp. 22–32, 1934, 1 pl.

Name: In honor of Prince Piero Ginori-Conti, who contributed to the progress of the borax industry of Italy.

Chemical Properties: Hydrous calcium borate, $Ca_2B_{14}O_{28}\cdot 8H_2O\cdot$ Analyses: (by Gallori) B_2O_3 63.00, CaO 15.40, H_2O 19.40, residue and loss 2.20; (by P. Rossone) B_2O_3 64.06, CaO 16.00, H_2O 19.27, CO_2 0.15, residue 1.07; total 100.55.

Crystallographic Properties: Monoclinic, in lozenge-shaped plates with acute angle of 78°.

Physical and Optical Properties: Color white.

Biaxial positive. $2V=42°\pm 2°$, $\alpha=1.517$, $\beta=1.524$ (calc), $\gamma=1.577$. Plane of the optic axes parallel to the cleavage (b, 010), with an angle between X and the edge of 51°.

Hd.=3.5, G=2.09.

Occurrence: As veins in sandstone associated with some calcite. The microstructure either in elongated prismatic laths or minutely granular. Occasional lozenge-shaped grains, especially in the powdery forms.

W. F. F.

Ferri-paraluminite

Pilipenko, P. P., Sulfate from Sokolowaja Mountain near Saratow. *Sci. Pub. Univ. Saratow,* vol. **6,** No. 3, pp. 167–179, 1927. Abs. *N. Jahr. Min.,* vol. **1,** pp. 297–8, 1928. (Original not seen.)

Chemical Properties: A sulfate of iron and aluminum, $(Al, Fe)_2O_3\cdot SO_3\cdot 15H_2O$. Analysis: SO_3 11.07, Al_2O_3 16.66, Fe_2O_3 13.39, FeO 0.57, CaO 1.35, MgO 0.82, H_2O 32.57, Insol. 23.24. Total 99.67.

Occurrence: Forms as slimy curds on the floor of a water basin, in crusts 1–3 cm. thick as a deposit from groundwaters. From Sokolowa Gora near Saratow, Russia

W. F. F.